The potential of electricity storage in Belgium

Dr. Kristof De Vos – KU Leuven & EnergyVille
Prof. Johan Driesen and Tom Brijs

Electrabel wil energie opslaan met kunstmatig eiland in Noordzee

Door Dimitri Reijerman, dinsdag 19 augustus 2014 15:18, 259 reacties, 32.529 views • Feedback

Electrabel wil voor de Belgische kust een kunstmatig eiland laten verrijzen voor energieopslag. In het donutvormige eiland wordt bij lage energieprijzen water uit het bassin weggepompt. Op momenten van energieschaarste loopt zeewater in het bassin en drijft het turbines aan.

Duits bedrijf opent Europa's grootste installatie voor opslag groene stroom

Door Dimitri Reijerman, woensdag 17 september 2014 15:55, 156 reacties, 19.689 views • Feedback

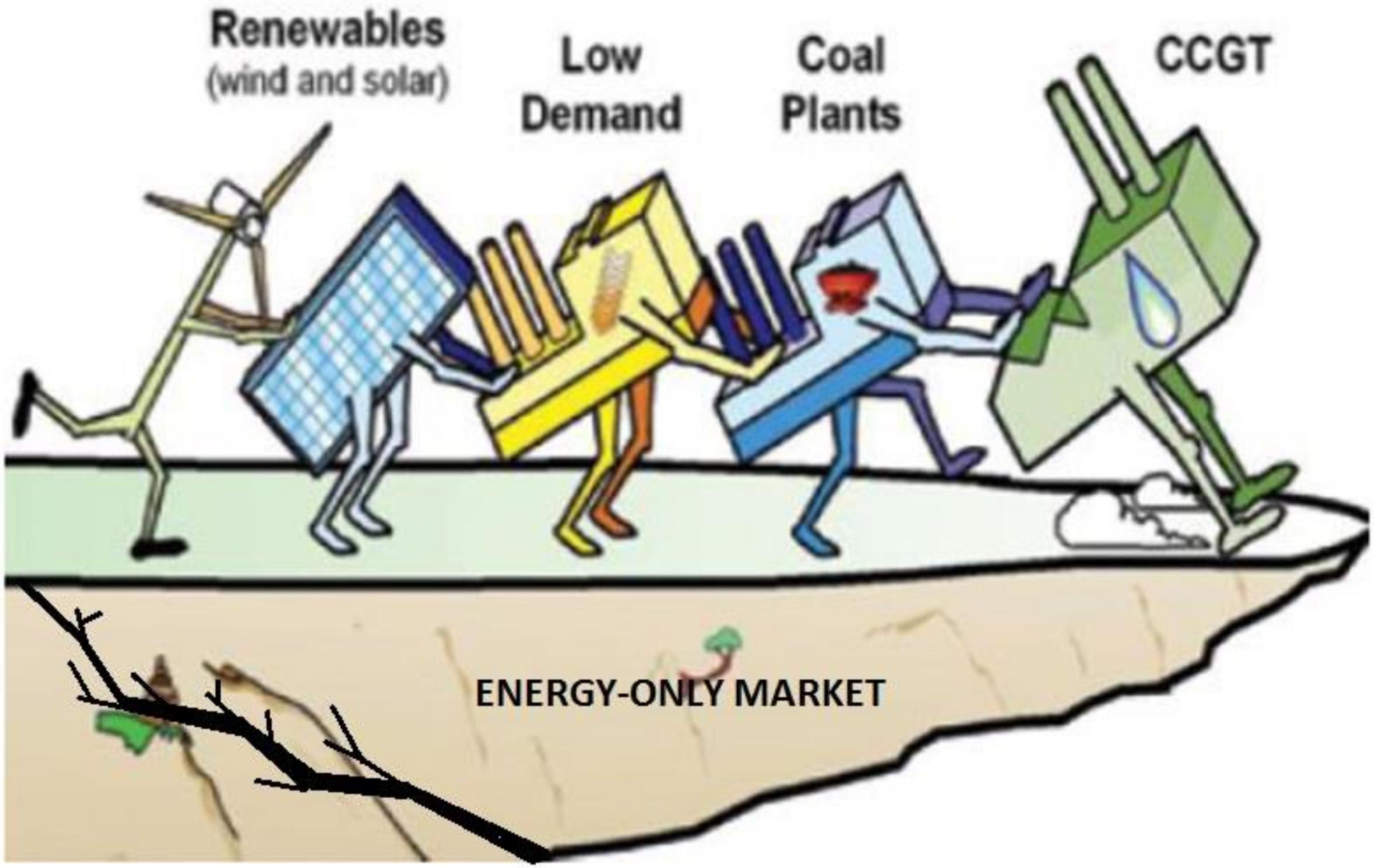
In Duitsland heeft het energiebedrijf Wemag AG naar eigen zeggen Europa's eerste grote energieopslag geopend waarin overtollige groene stroom afkomstig van windmolens en zonnepanelen tijdelijk kan worden bewaard. De capaciteit bedraagt 5MWh.

Tesla wil accupacks gaan produceren voor thuisopslag elektriciteit

Door Dimitri Reijerman, donderdag 12 februari 2015 19:37, 256 reacties, 34.745 views • Feedback

Tesla heeft een ontwerp klaar voor een accupack dat bedoeld is om in een huishouden tijdelijk stroom op te slaan. Het accupack zou dienst kunnen doen voor het opslaan van elektriciteit die via zonne-energie is opgewekt.

Power system revolution



Scope and objective

CONTEXT

Variability of Renewable Energy Sources:
wind and photovoltaics

Need for flexibility:
power plants, demand response and storage

European electricity system:
interconnected transmission grid and market integration

Objective - Insight in the potential role of storage in the Belgian electricity system

Introduction

- Definition
- Applications
- Need

Technical aspects

- Technologies
- Belgian projects
- Worldwide projects

Economic aspects

- Cost structure
- Remuneration
- Business case

Regulatory aspects

- Regulatory barriers
- Administrative barriers

Outcome: SWOT analysis of selected technologies
Policy Recommendations

EnergyVille

PART I.

Introduction

The growing share of variable generation

Table 1: Installed capacity (GW) and annual electricity generation (TWh) of wind and PV in selected European countries by the end of 2013 (based on data published by ENTSO-E 2015)

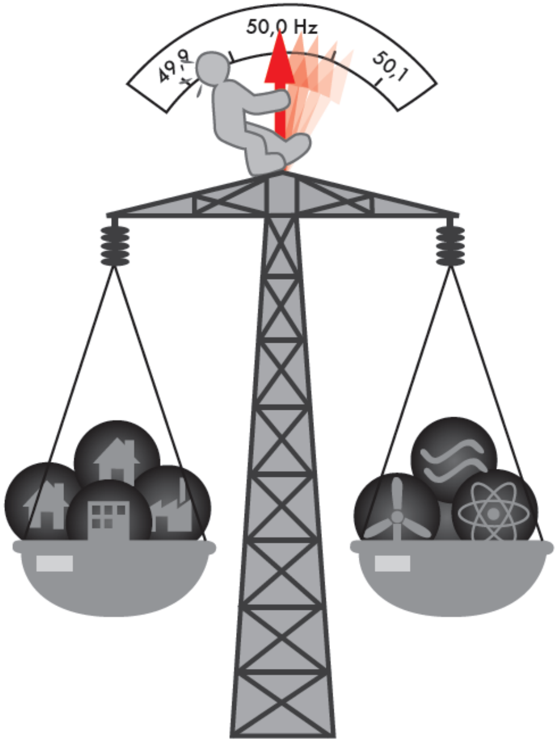
	wind				solar (mostly PV[3])			
	[GW]	[TWh]	penetration [%]		[GW]	[TWh]	penetration [%]	
			mean[1]	max[2]			mean[1]	max[2]
Germany	33,1	50,8	9,16	101,85	35,9	31	5,59	110,46
Belgium	1,7	3,6	4,18	27,87	2,7	2,4	2,78	44,26
France	8,2	15,9	3,21	27,70	4,4	4,7	0,95	14,86
Denmark	4,8	11	33,95	436,36	0	0	0,00	0,00
Portugal	4,4	11,7	23,78	125,71	0,3	0,4	0,81	8,57
Spain	22,8	54,7	20,89	133,33	6,9	12,8	4,89	40,35
Ireland	1,8	4,5	17,31	105,88	0	0	0,00	0,00
Italy	8,5	14,8	4,69	44,50	18,4	21,2	6,71	96,34

[1] average electric energy penetration: annual electricity generation in terms of total consumption; [2] max penetration: installed capacity in terms of minimum consumption; [3] solar in Spain includes 2.3 GW Concentrated Solar Power (CSP)

De Vos, 2014

The system need for flexibility

- Real-time balance of generation and load is a prerequisite for a stable frequency level
  - Deviations from nominal frequency results in system failures, and eventually a system black out
- Up to now, variable demand has always been covered by flexible power plants
  - Generation adapts to load
  - Flexible gas-fired power plants
- Increasing penetration of variable renewable generation
  - Replacing controllable by variable supply
    - Periods with excess or shortage energy
    - Prediction errors



NEED FOR ADDITIONAL AND ALTERNATIVE MEANS FOR FLEXIBILITY!

The system need for flexibility

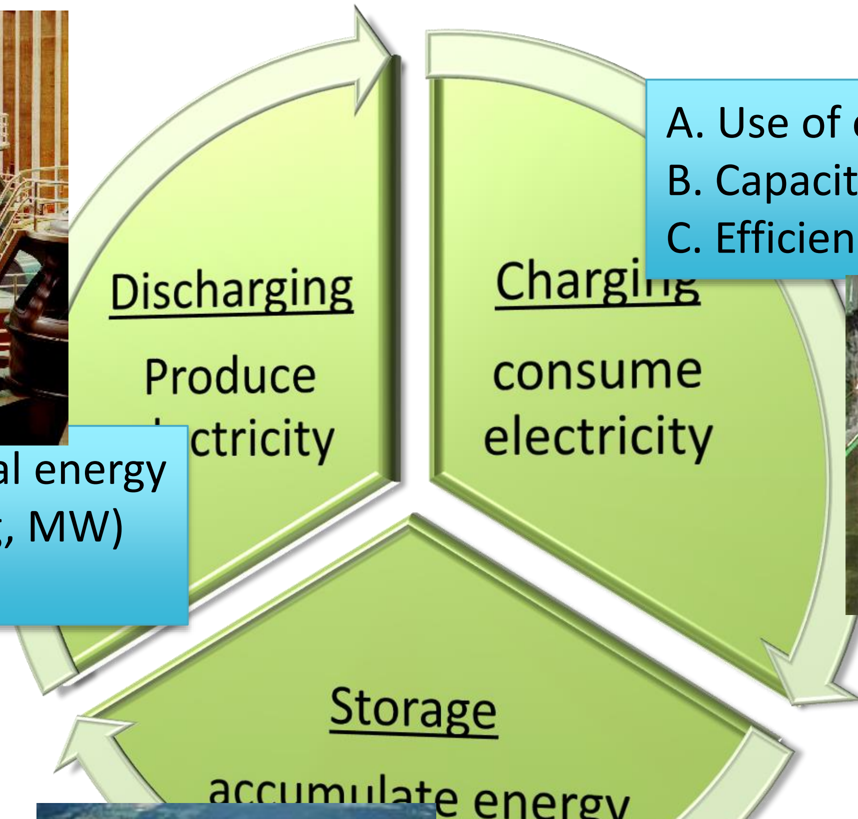
SYSTEM IMBALANCES	FACILITATORS	FLEXIBLE TECHNOLOGIES
Equipment Outages	Transmission & Interconnections	conventional and renewable generators (CCGT, OCGT,wind,…)
Demand Variations	Market Design	storage (pumped-hydro storage, CAES,...)
RES-E Variations		demand-side management (industry, residential,…)

De Vos, 2013

Need for storage is to be seen in broader context

- Technology and cost evolutions of storage
- Evolutions competing technologies
- Power system evolution (supergrid versus smartgrid)

Electricity storage: definition

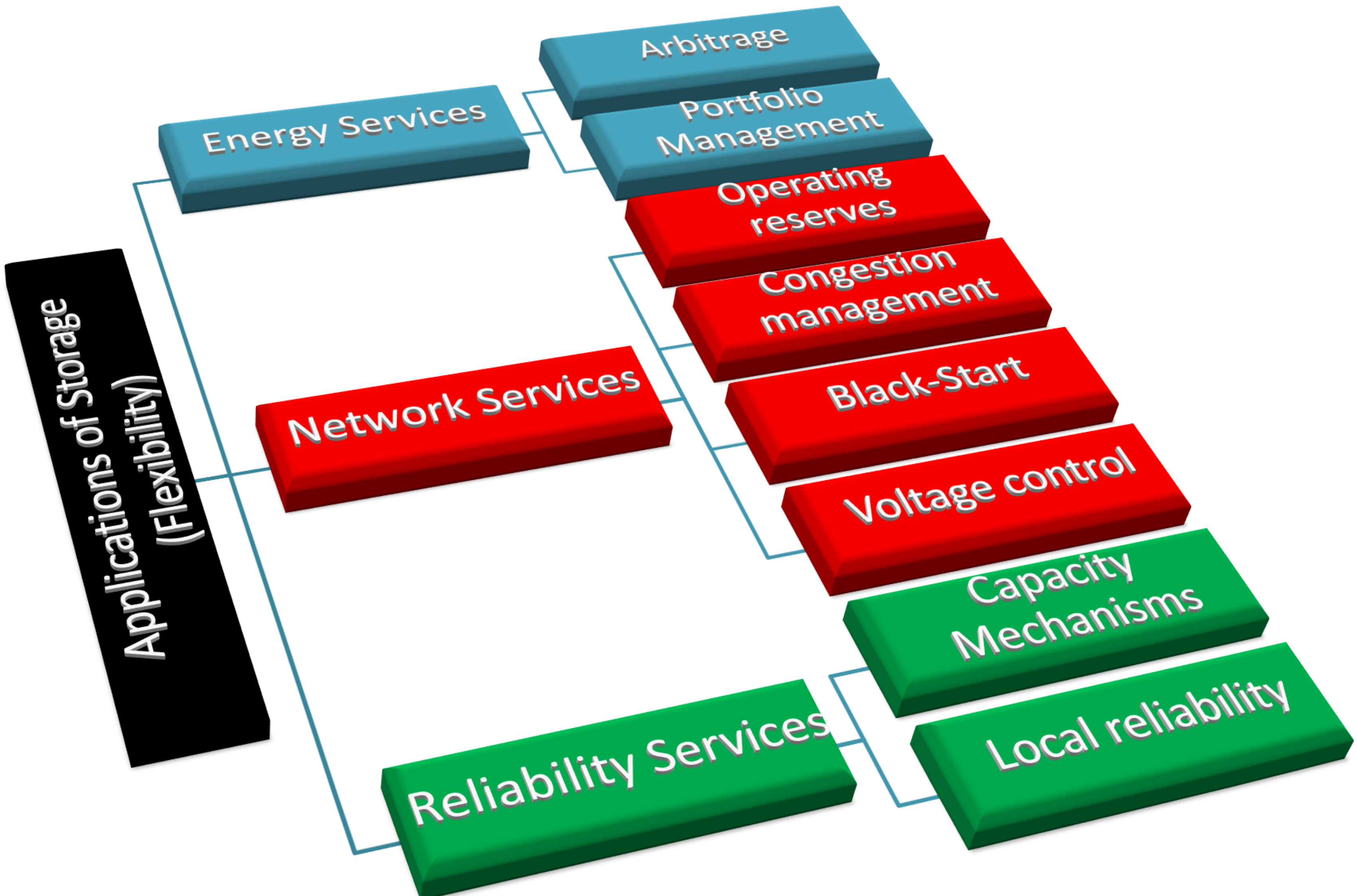


A. Use of electrical energy
B. Capacity (power rating, MW)
C. Efficiency, energy loss

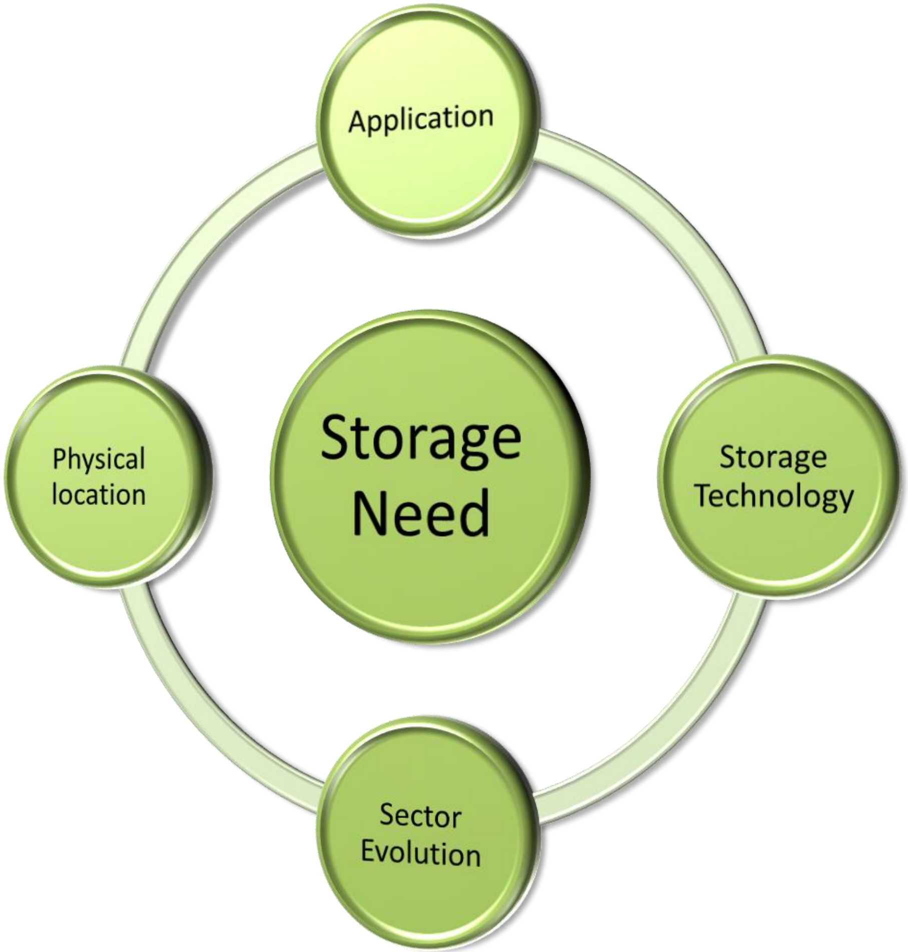
A. Generation of electrical energy
B. Capacity (power rating, MW)
C. Efficiency, energy loss

A. Any form of energy
 e.g. thermal, kinetic, chemical,…
B. Energy buffer (MWh)

Applications in a liberalized market



Quantification of system need for storage



Van Stiphout, De Vos, et al. 2015

- Quantification of the need for storage is a complex problem determined by different parameters
- Integration of storage and flexibility in Generation Expansion Models (operations research)
- Need for new software tools for determining future electricity market scenarios
  - Prediction errors RES
  - Power plant constraints
  - Network constraints
  - New technologies
    - Distribution level
    - Storage and demand-response

EnergyVille

PART II.

Storage technologies and their techno-economic characteristics

Technologies and technical characteristics

- Mechanical
  - PHS
  - CAES
  - Flywheel
- Chemical
  - P2G
  - Fuel cell
- Electrical
  - SMES
  - Supercap
- Electro-chemical
  - Battery
  - Flow battery
- Thermal

Power	Discharge time	Response Time	Efficiency	Lifetime	Maturity
GW, MW, kW	m, d, h, min, sec	min, sec, ms	%	year	high, low

Mechanical: Pumped Hydro Storage (PHS)

Principle

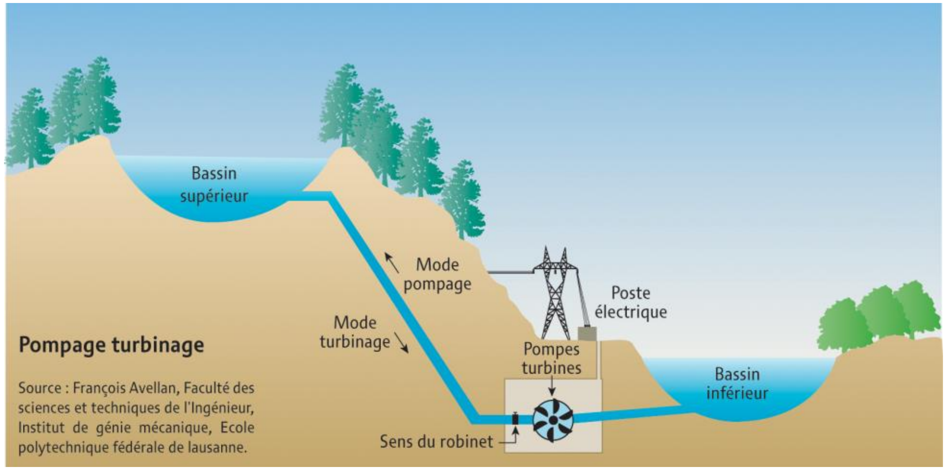
1. Pump water
2. Store in a lake
3. Drive turbine: generator

Advantages

- High maturity
- High efficiency
- Large scale

Disadvantages

- Geographical constraints
- Low energy density



Power	MW - GW
Discharge time	Days - hours
Response time	Sec – min
Efficiency (%)	70 – 85%
Lifetime	20 – 50 years
Maturity	Very High

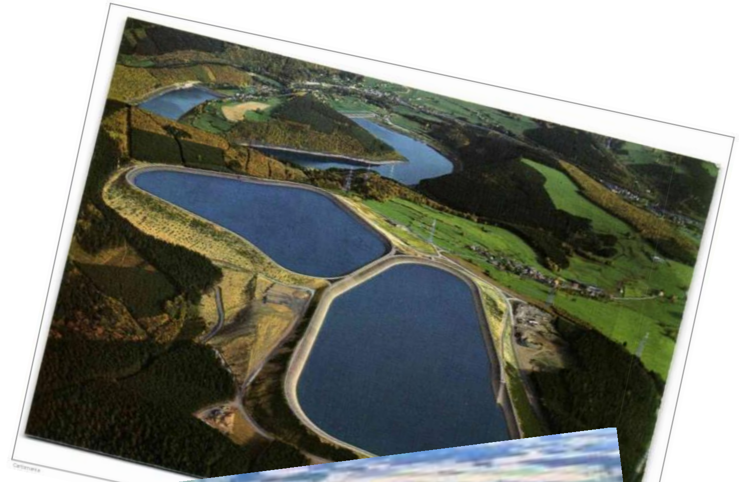
Belgian case studies

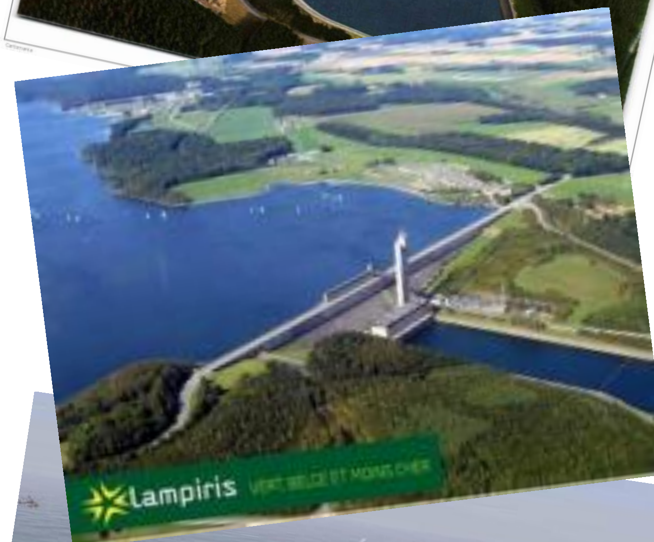
Coo-Trois-Ponts (Electrabel):
*Gen. Capacity: 470 MW (Coo I)+ 690 MW (Coo II)
*Energy buffer: 2,3 GWh (Coo I) + 2,7 GWh (Coo II)

Possible extention (study phase): Coo III
*Gen. Capacity:600 MW
*Energy buffer: 3 GWh

Plate Taille (Lampiris)
*Gen. Capacity: 144 MW
*Energy buffer: 0,8 GWh

iLand (study phase)
*Gen. Capacity: 550 MW
*Energy buffer: 2 GWh





Mechanical: Compressed Air Energy Storage (CAES)

- **Principle**
  1. Compress air
  2. Store under pressure
  3. Drive turbine (+gas): generator

  New: Adiabatic CAES

- **Advantages**
  - Large scale
  - High maturity (diabatic)
- **Disadvantages**
  - Low efficiency
  - Geographical constraints
  - Complementary infrastructure: gas turbine and gas network
- **Projects:**
  - Huntorf, DE (320 MW), McIntosh, USA (110 MW), Adiabatic Plant ADELE under construction 90 MW

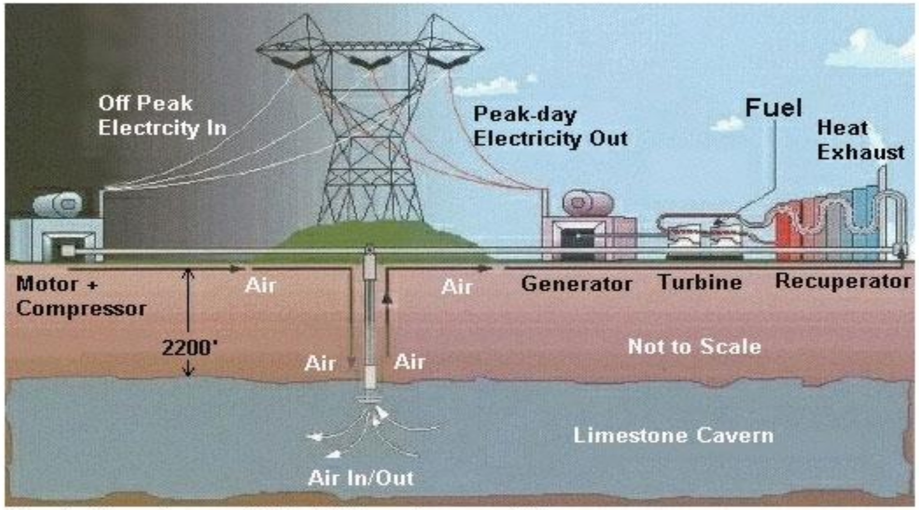


Photo Courtesy of CAES Development Company

Power	MW - GW
Discharge time	Days - hours
Response time	min
Efficiency	40 – 70%
Lifetime	20 – 40 years
Maturity	Very High

Mechanical: Flywheel

20 MW Plant, Hazle USA

Principle

1. Motor
2. Kinetic energy
3. Generator

Advantages

- High response time
- High power density
- Efficiency

Disadvantages

- Energy density
- Self discharge

Projects:

- New York, 20 MW (frequency control), Offalay, IE under construction

Power	kW - MW
Discharge time	sec - min
Response time	msec
Efficiency	75 – 88%
Lifetime	15 – 20 years
Maturity	High

Chemical :Power To Gas (P2G)

Principle

1. $H_2O \rightarrow H_2 + O_2$ and $H_2 + CO_2 \rightarrow CH_4$
2. Store as gas (inject in gas network)
3. ??? (open cycle)

Advantages

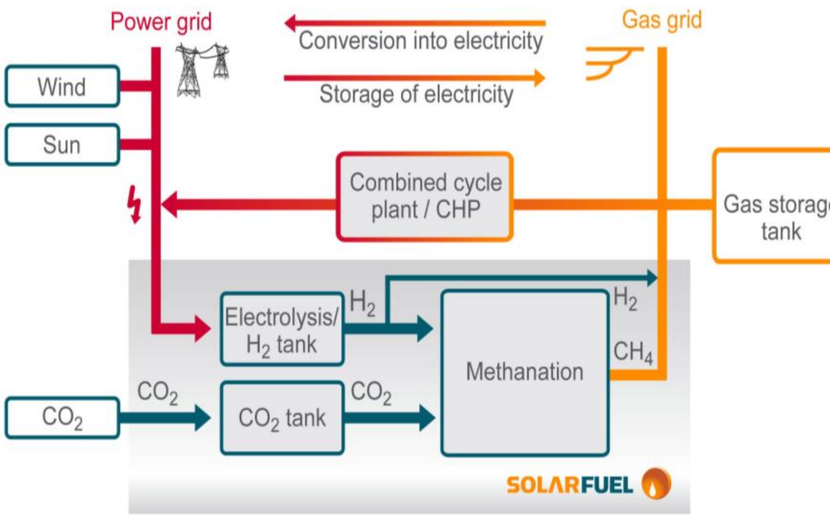
- Unlimited energy buffer
- Integration with industrial processes

Disadvantages

- Low maturity, low efficiency
- Complementary infrastructure: gas or hydrogen network and gas turbines

Projects:

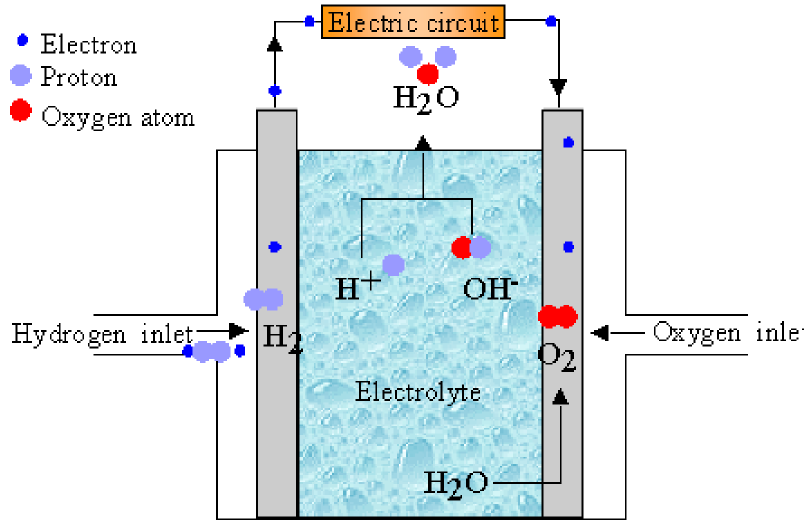
- Werlte, DE 6,3 MW (waste-biogas), Utsira, NO, 48 kW (excess RES)



Specht, M. et al. 2012

Power	kW - MW
Discharge time	Weeks - months
Response time	Sec - min
Efficiency	20 – 60%
Lifetime	5 – 30 years
Maturity	Very low

Chemical: Fuel Cell



Specht, M. et al. 2012

Principle

1. ??? (open cycle)
2. Store gas (gas network)
3. $H_2 + O_2$ ➔ H_2O and CH_4 ➔ $H_20 + CO_2$

Advantages

- Energy density
- Integration with industrial processes

Disadvantages

- Low maturity, efficiency
- Complementary infrastructure: gas, hydrogen network

Projects:

- South Windsor, US 200 KW, Lillo BE 1 MW Solvay (hydrogen recycling)

Power	kW - MW
Discharge time	hours
Response time	Sec - min
Efficiency	50 – 70%
Lifetime	5 – 15 years
Maturity	Low

Electrical: SMES and Supercaps

Principle

- SMES: electrical storage based on magnetic induction and superconduction;
- SC: electric based on electric field in capacitor;

Advantages

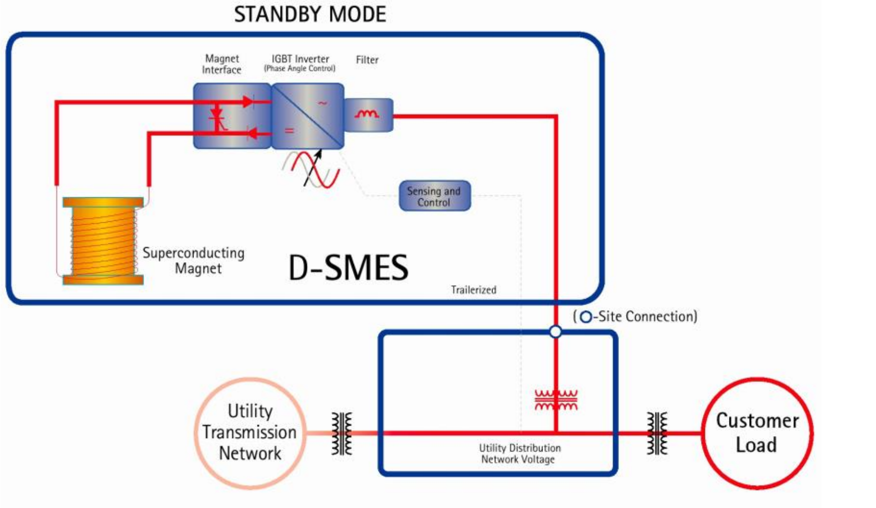
- Fast response time
- Power density
- Efficiency

Disadvantages

- Energy density

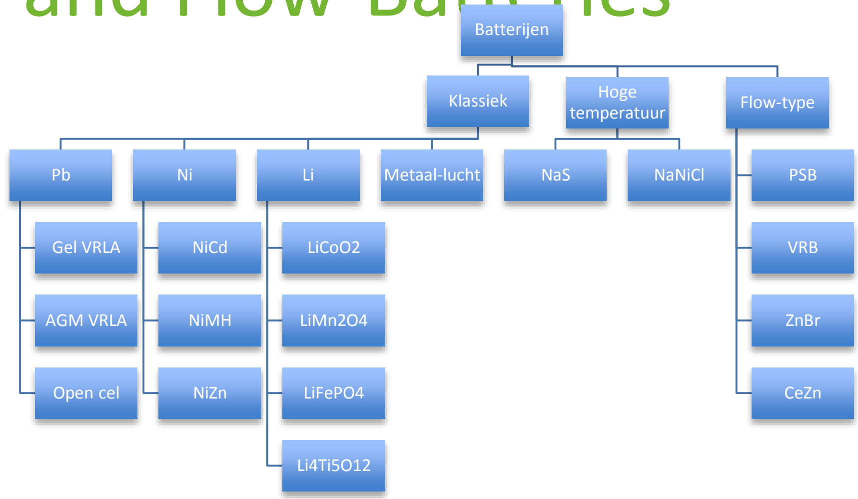
Projects:

- Wisconsin, US 800 KW (network support); La Palma, ES 4 MW (network support)



Power	kW - MW
Discharge time	sec -min
Response time	ms
Efficiency	90 – 97%
Lifetime	20 – 40 years
Maturity	Average

Electro-chemical: Batteries and Flow-Batteries



Principle

- process based on flow of electrons between anode and cathode (electrolyte)

Advantages

- Scalability
- Efficiency, Response time
- Power and energy density

Disadvantages

- Lifetime (cycles)
- Safety

Projects:

- Rokkasho, JP 34 MW (excess RES), West Meckleburg, DE (frequency control)

	NaS, Li-Ion	Flow
Power	kW - MW	kW - MW
Discharge time	hours	hours
Response time	ms	ms
Efficiency	75 – 85 %(NaS) 80 – 95 %(Li-ion)	70-85%
Lifetime	10 – 20 years	5 – 20 years
Maturity	High	Average

Thermal: Liquid Air Energy Storage (LAES)

Principle

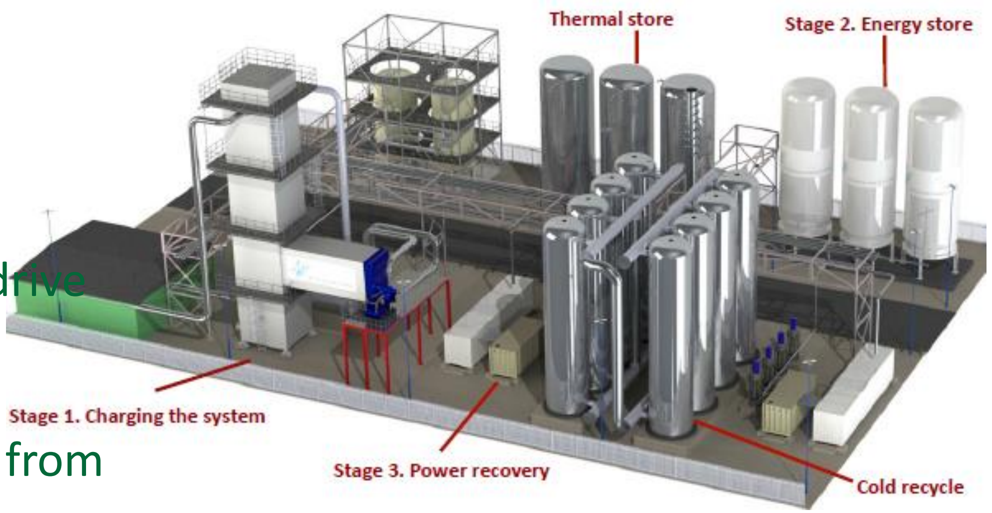
1. Cooling: liquification of air
2. Low pressure storage
3. Pump to high pressure gas to drive turbine

Advantages

- Integration of heat and cold from industrial processes
- Energy density

Disadvantages

- Maturity
- Efficiency



West Highland Power 2012

Power	kW - MW
Discharge time	hours
Response time	min
Efficiency	50 – 80 %
Lifetime	25 – 30 years
Maturity	Low

Projects:

- Scotland, 350 kW and upscale planned towards 5MW

Cost of storage

	Installation Cost		Maintenance Cost	Cycle Efficiency
	w.r.t. Power	w.r.t. Energy	Cost	Efficiency
	[€/kW]	[€/kWh]	[€/kW/year]	[%]
Mechanic				
PHS	400 - 5000	5 - 100	10 - 15	70 - 85
CAES	400 - 1200	2 - 50	10 - 25	40 - 70
Flywheel	100 - 300	1000 - 3500	20 - 30	75 - 88
Chemical				
P2G	550 - 1600	1 - 5	-	20 - 60
Fuel Cell	5000 - 10000	5000 - 10000	-	50 - 70
Electrical				
SMES	200 - 400	1000 - 10000	10 - 25	90 - 97
Supercapacitors	100 - 300	300 - 2000	10 - 15	93 - 97
Elektrochemic *				
NaS	1000 - 3000	300 - 500	10 - 50	75 - 85
Li-ion	1200 - 4000	400 - 2000	20 - 60	80 - 95
Flow battery	600 - 2500	150 - 1000	10 - 55	70 - 85
Thermic				
LAES	900 - 1900	260 - 530	-	50 - 80

**Large margins due to low maturity of technologies (demonstration or pilot projects)*

**Compared to: CCGT : 700 – 1200 €/kW ; Nuclear 3800 – 6000 €/kW

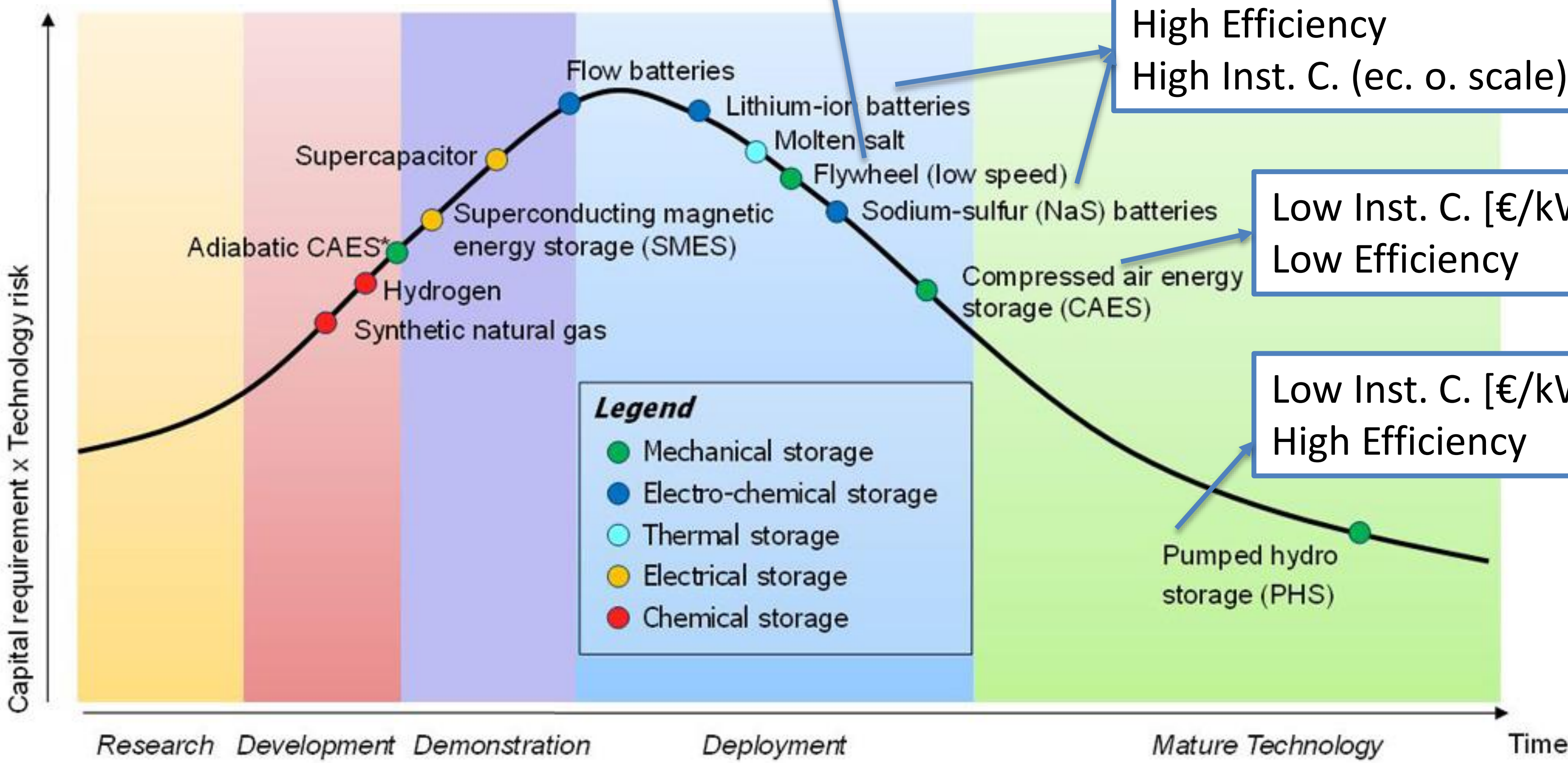
Maturity

Low Inst. Cost [€/kW]
High Inst. Cost [€/kWh]
High Efficiency

High Efficiency
High Inst. C. (ec. o. scale)

Low Inst. C. [€/kWh]
Low Efficiency

Low Inst. C. [€/kWh]
High Efficiency



Source: SBC Energy Institute Analysis

Conclusions on storage technologies

Transmission level

- PHS largest potential for large-scale storage
  - Cost-efficiency (⇔ CAES)
  - Geographical constraints
- Flywheels, SMES and Supercaps for specific applications such as network stability

Distribution level

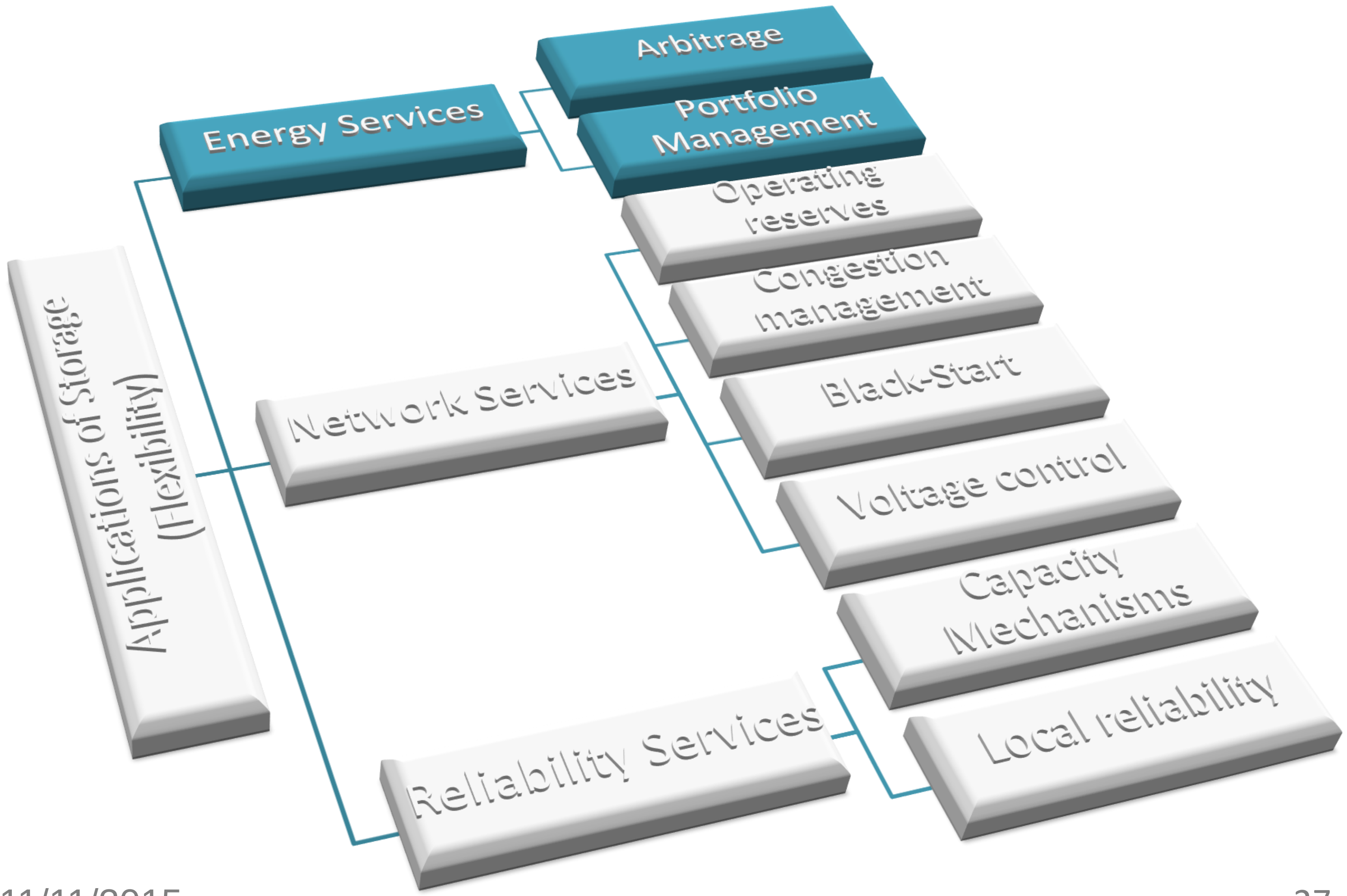
- Batteries provide largest potential for distributed storage
  - Various applications
  - Economies of scale
- P2G, LAES, Fuel Cell require further Research and Development

EnergyVille

PART III.

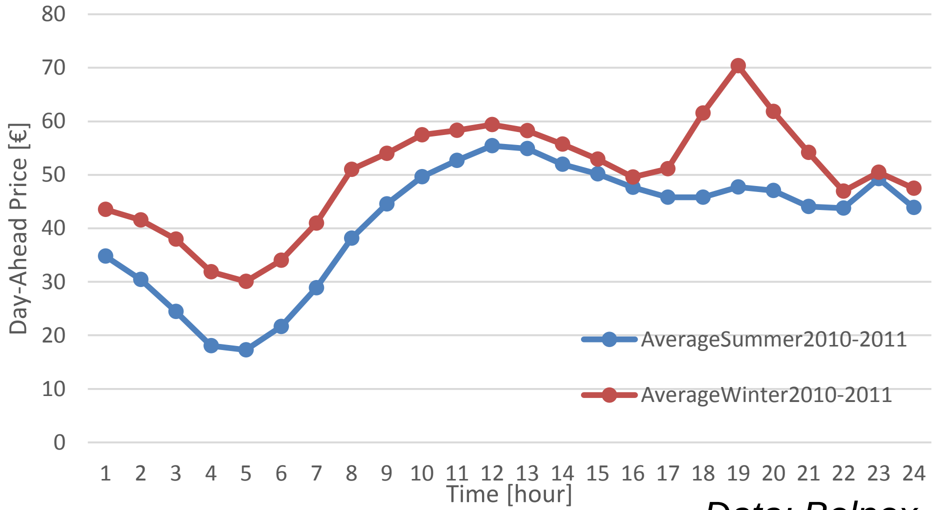
Building a business case for storage

Applications in a liberalized market



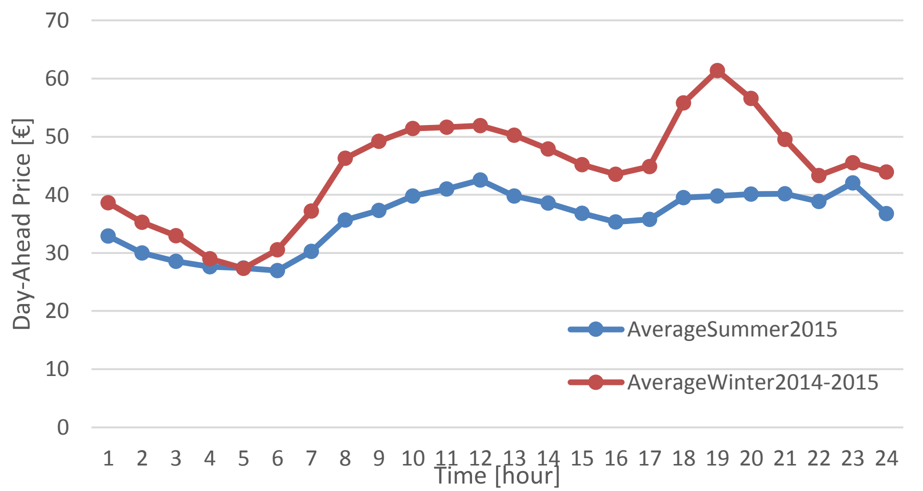
Energy services: arbitrage

- Day-Ahead Market
  - Night: charge
  - Day: discharge
  - ~Electricity demand



Data: Belpex

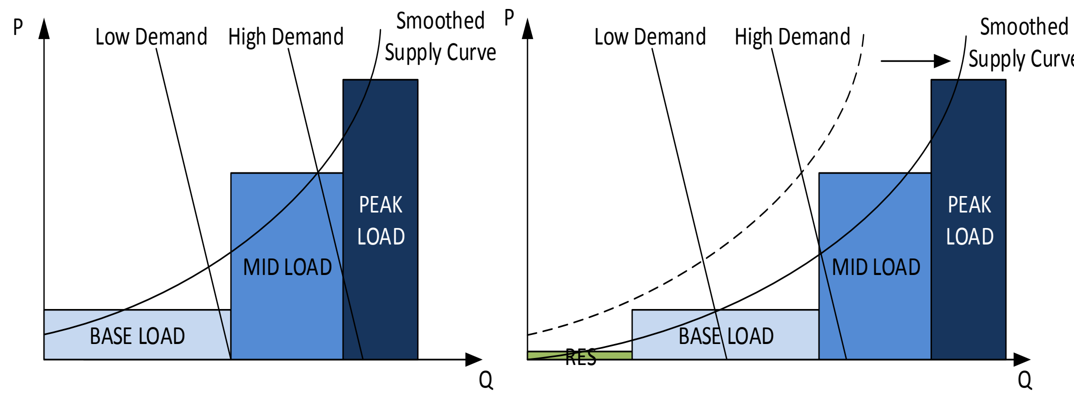
- Decreasing day-night difference
  - Impact profitability
  - Corr. Expected RES



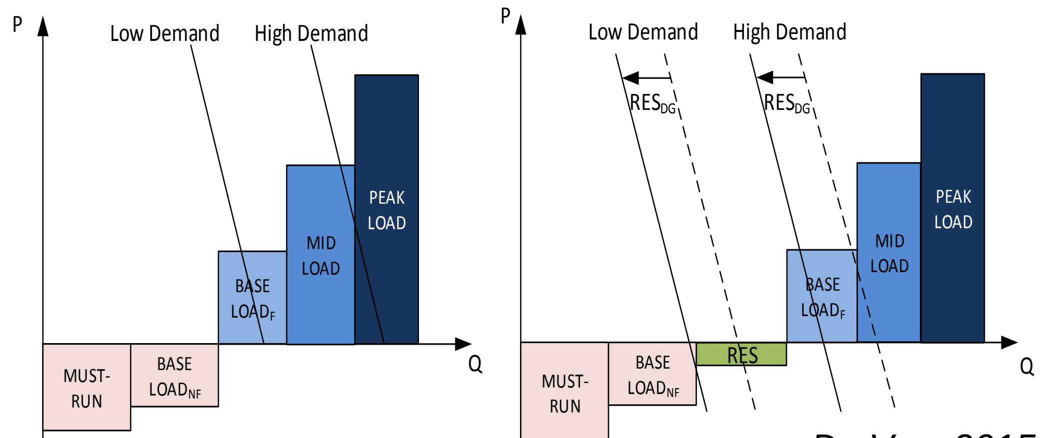
Data: Belpex

Merit Order Effect

- Renewable Generation
  - Expected price volatility may change operation strategy
    - Expected Demand
    - Expected RES
    - Price forecasts



- Negative Prices
  - Must Run
  - Base Load
  - RES support
  - Priority feed-in RES



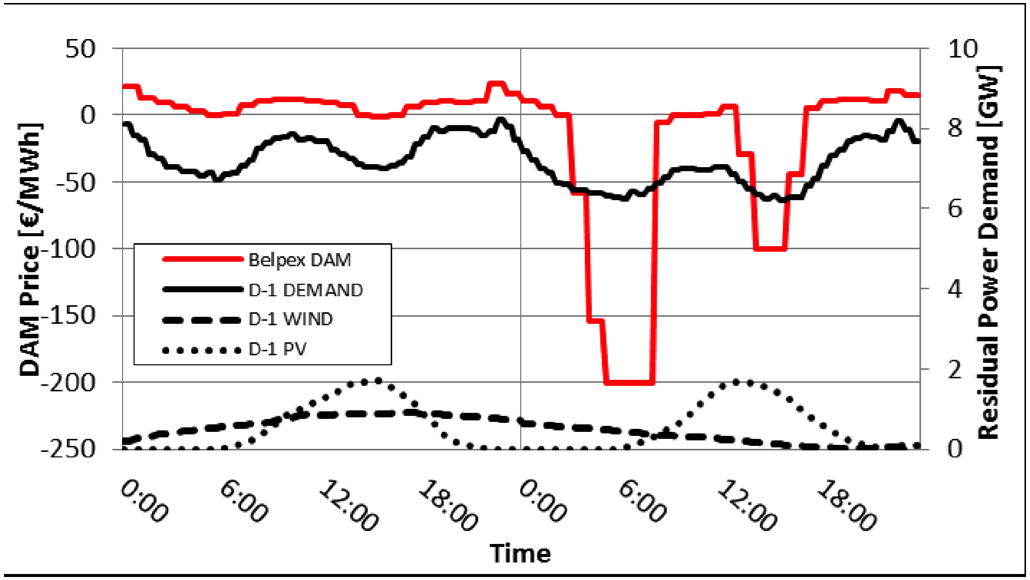
De Vos, 2015

Negative Prices

- June 15-16, 2013
  - Low demand (holiday)
  - High wind and PV
  - Market coupling
    - BE – FR - DE

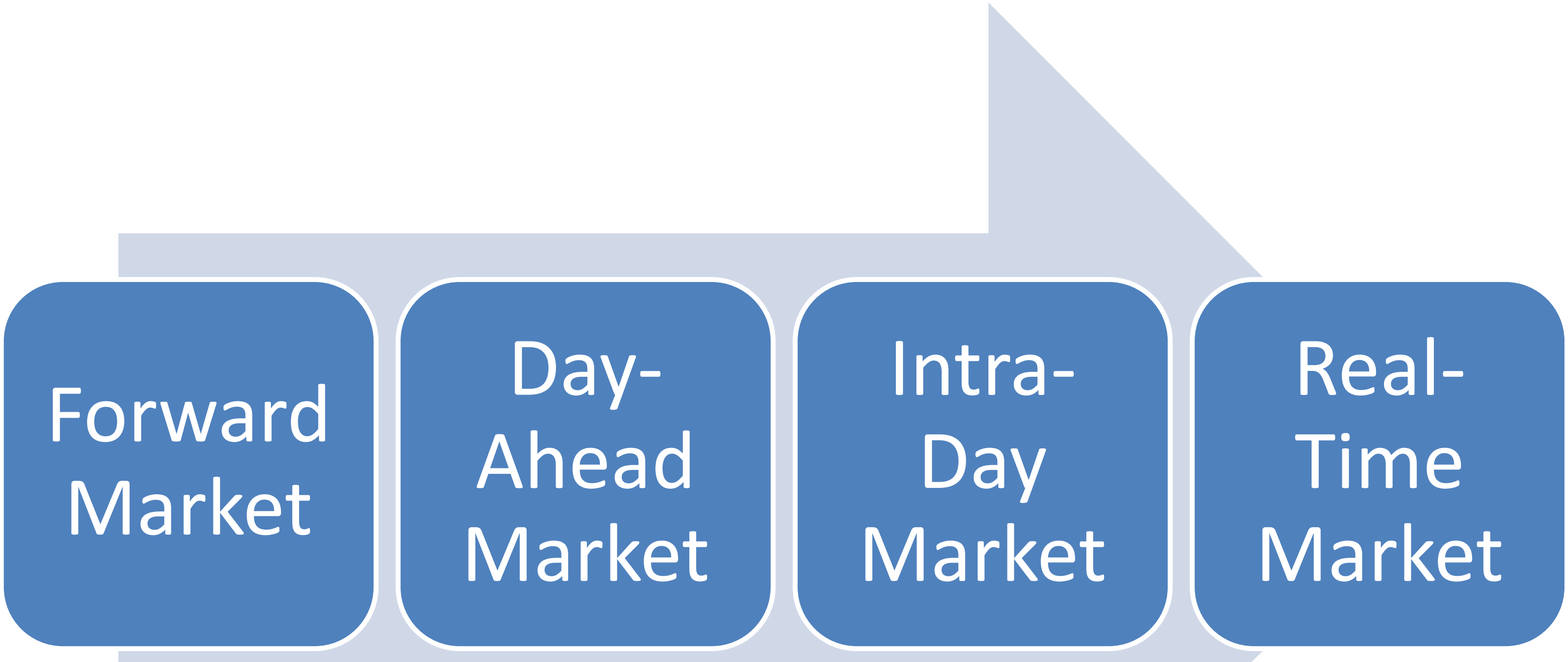
Joint Statement of APX, Belpex and EPEX Spot – negative baseload prices on 16 June 2013

High price differences were observed in the Central Western European (CWE) region, with baseload prices in France and Belgium being -40.99€/MWh, in Germany -3.33€/MWh and the Netherlands 36.16€/MWh for delivery on Sunday 16 June 2013.



- Rare event (hours)
  - 2015: 0
  - 2014: 2
  - **2013: 15**
  - 2012: 7

Energy services: Arbitrage



Moving towards more complex operation strategies adapting consumption and generation schedule to expected prices.

Energy services: portfolio management

Long term

- Portfolio investments
  - Demand scenario
  - RES scenario
  - “Make or buy” decision
- Optimize portfolio investments
  - E.g. avoid investment in gas-fired power plants to cover peak demand and renewable injection.

Medium term

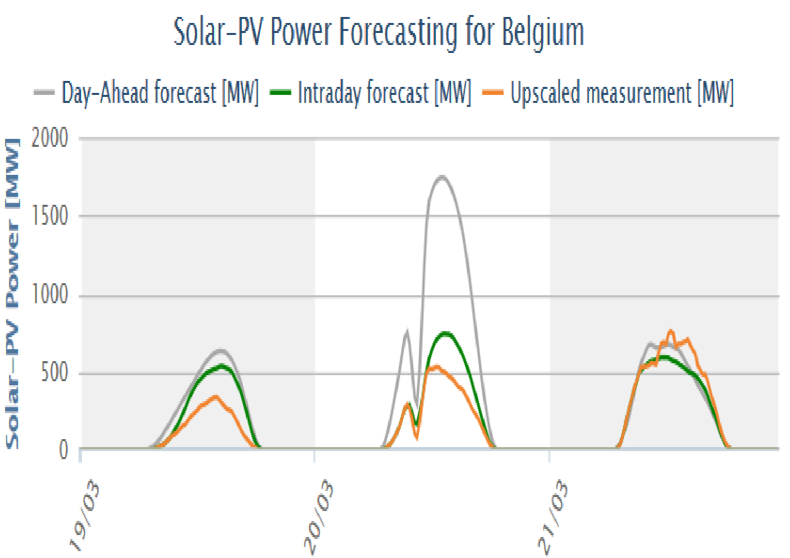
- Portfolio scheduling
  - Predicted RES
  - Predicted demand
  - Availability power plants
- Optimize generation schedule
  - E.g. avoid start-up of an expensive peak power plant

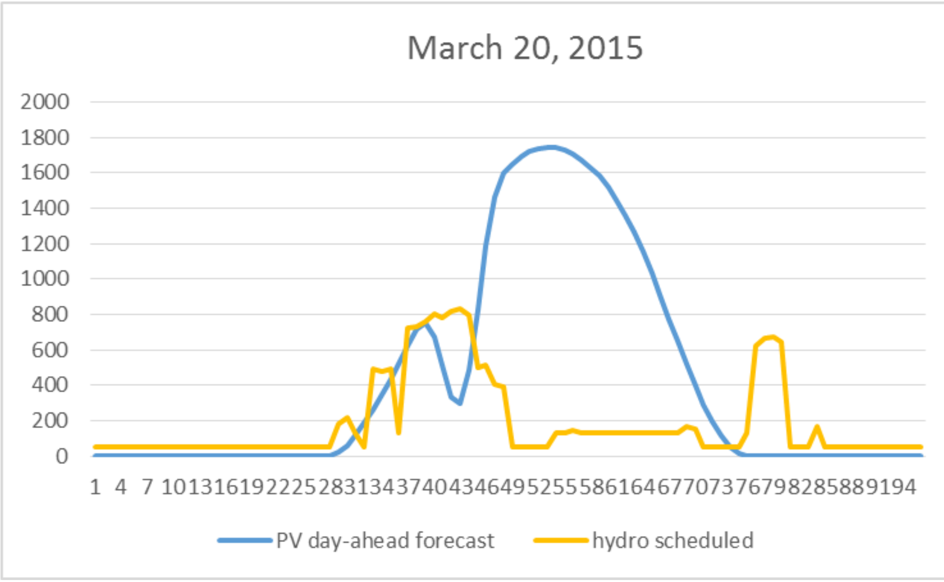
Portfolio management: scheduling

Stroom kan vrijdag uitvallen door zonsverduistering

17/03/2015 om 06:00 door RH

Print

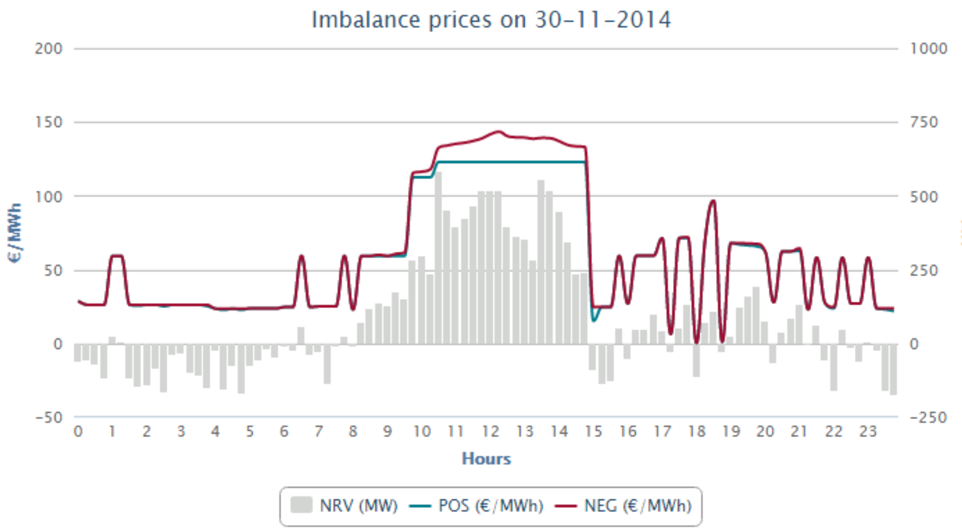




Energy services: portfolio management

Short term

- real-time portfolio balancing
  - Prediction errors RES
  - Prediction errors demand
  - Unexpected outages
- Optimize real-time portfolio balance
  - E.g. Avoid the start-up of peak power plant or imbalance price risk.

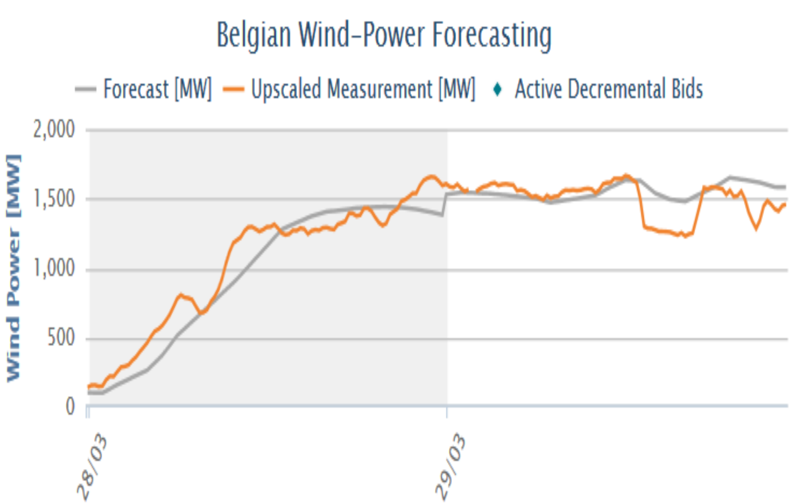


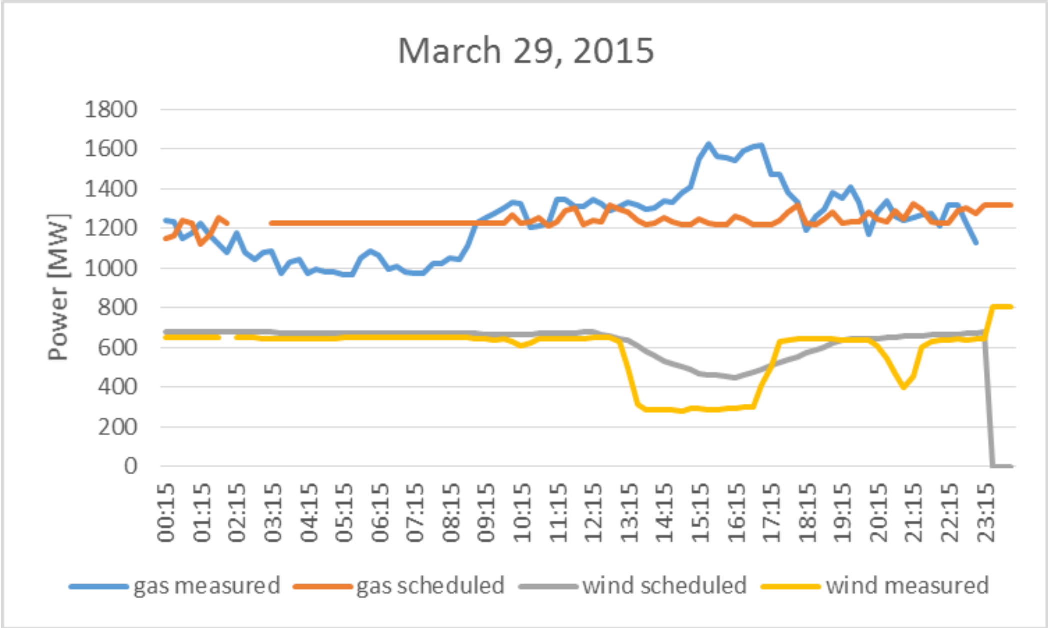
Portfolio management: balancing

Weekend eindigt stormachtig

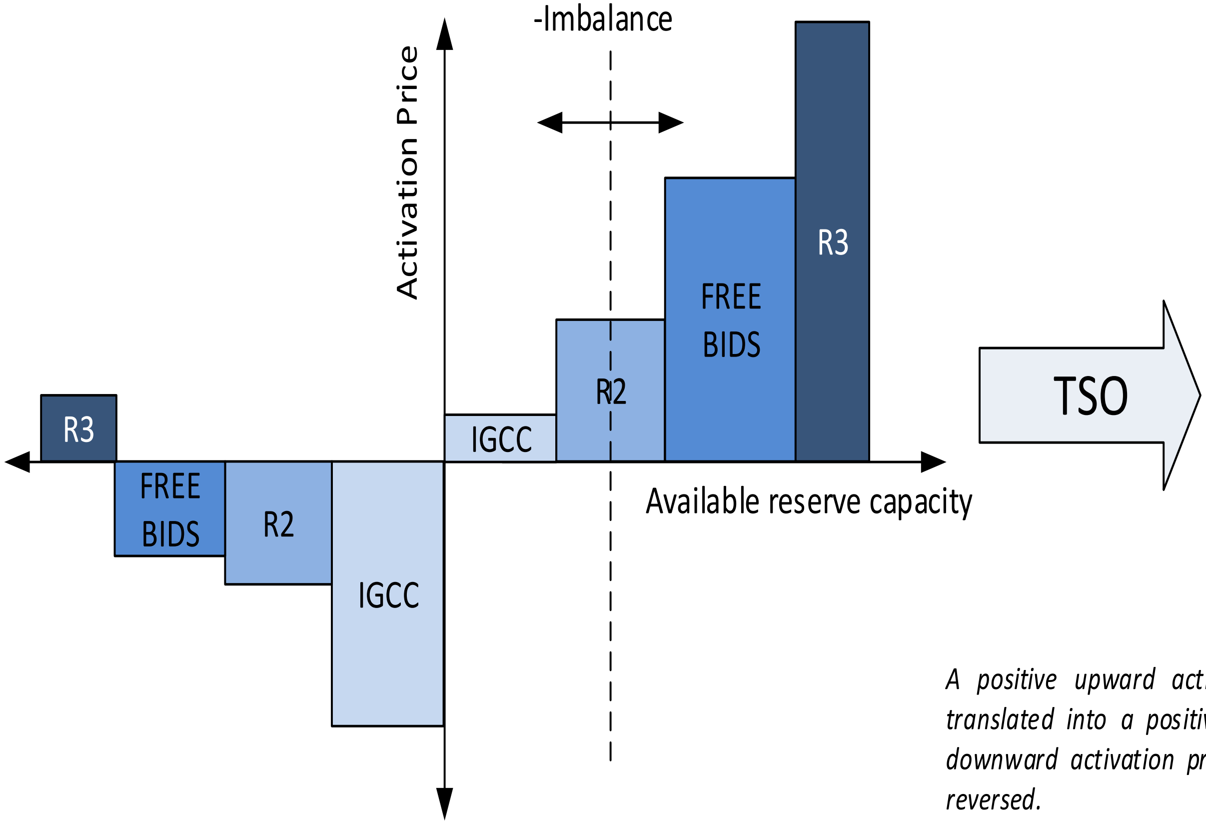
29-03-15, 09.18u - Bron: Belga

LEES LATER ★





Energy services: portfolio management



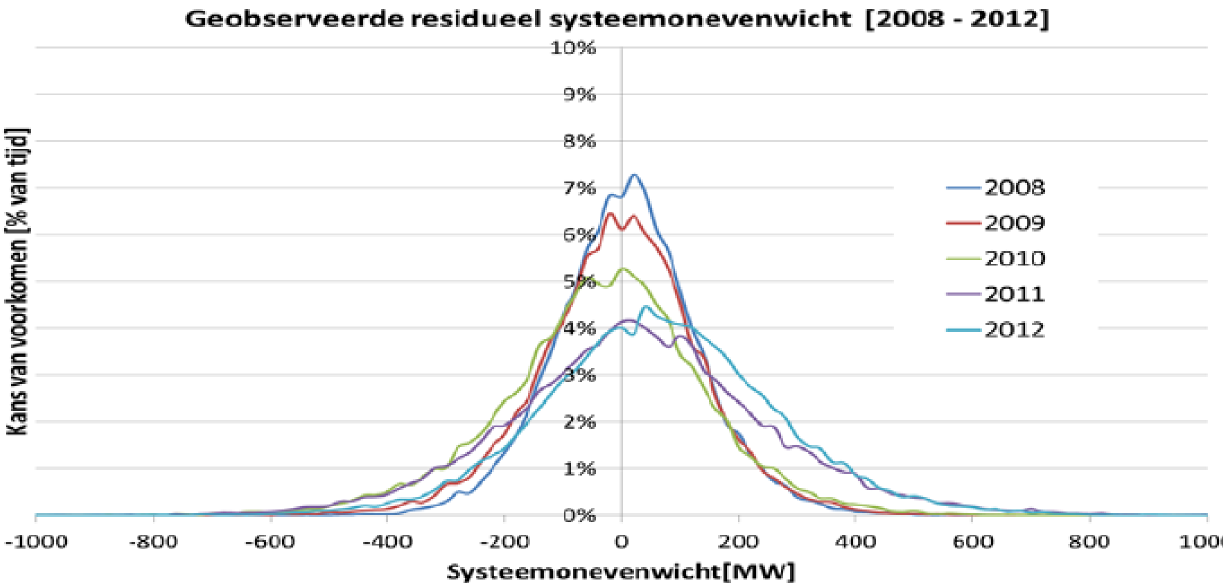
		SYSTEM	
		EXCESS	SHORTAGE
BRP	EXCESS	MDP TSO pays BRP	MIP TSO pays BRP
BRP	SHORTAGE	MDP BRP pays TSO	MIP BRP pays TSO

A positive upward activation price and negative downward activation price is translated into a positive settlement tariff (MIP and MDP). In case of a positive downward activation price, the settlement tariff is negative and money flows are reversed.

Energy services: portfolio management

- Increasing RES
  - Prediction errors
  - Increased need for reserve capacity
  - Decreasing conventional power

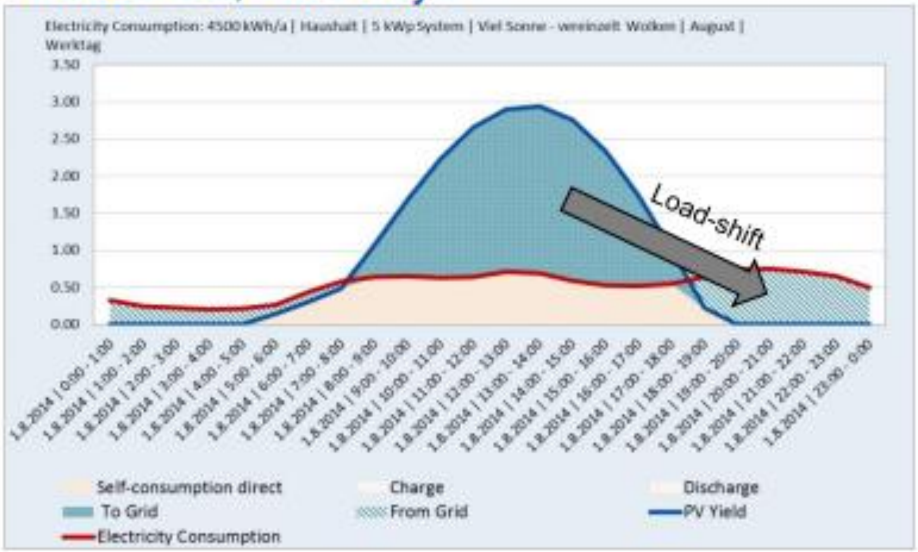
- Business case for flexibility: storage
  - Portfolio management
    - Minimize imbalance volume
  - Arbitrage
    - Direct market participation



Retail market: self-consumption

- Interaction with tariff design
  - Net metering
  - Injection price and tariff
  - New price and tariff design
    - Time of Use
    - Capacity-based
  - Subsidy for storage
    - E.g. Germany

Decentralized Rooftop Market
- Household, Weekdays -

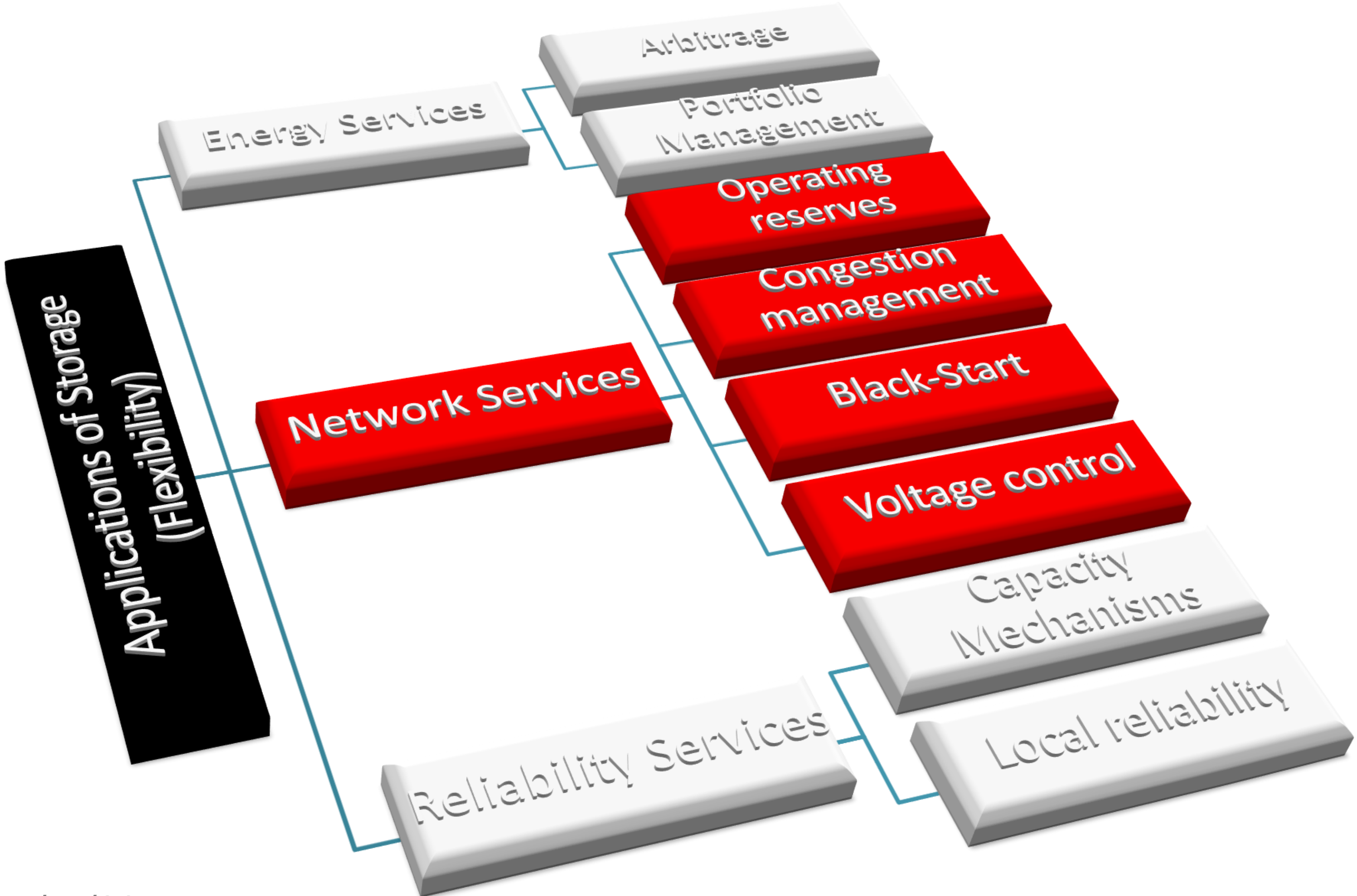


Low correlation with electricity generation

→ Storage is required to shift the load

Bryan Ekus, 2013

Applications in a liberalized market



Operating Reserves 2015

Powering a world in progress

R1 – Frequency Containment Reserve (94 MW)

Activation Order

R2 – Frequency Restoration Reserve (140 MW)

Free bids (not guaranteed)

R3 – Frequency Restoration Reserve (400 MW)

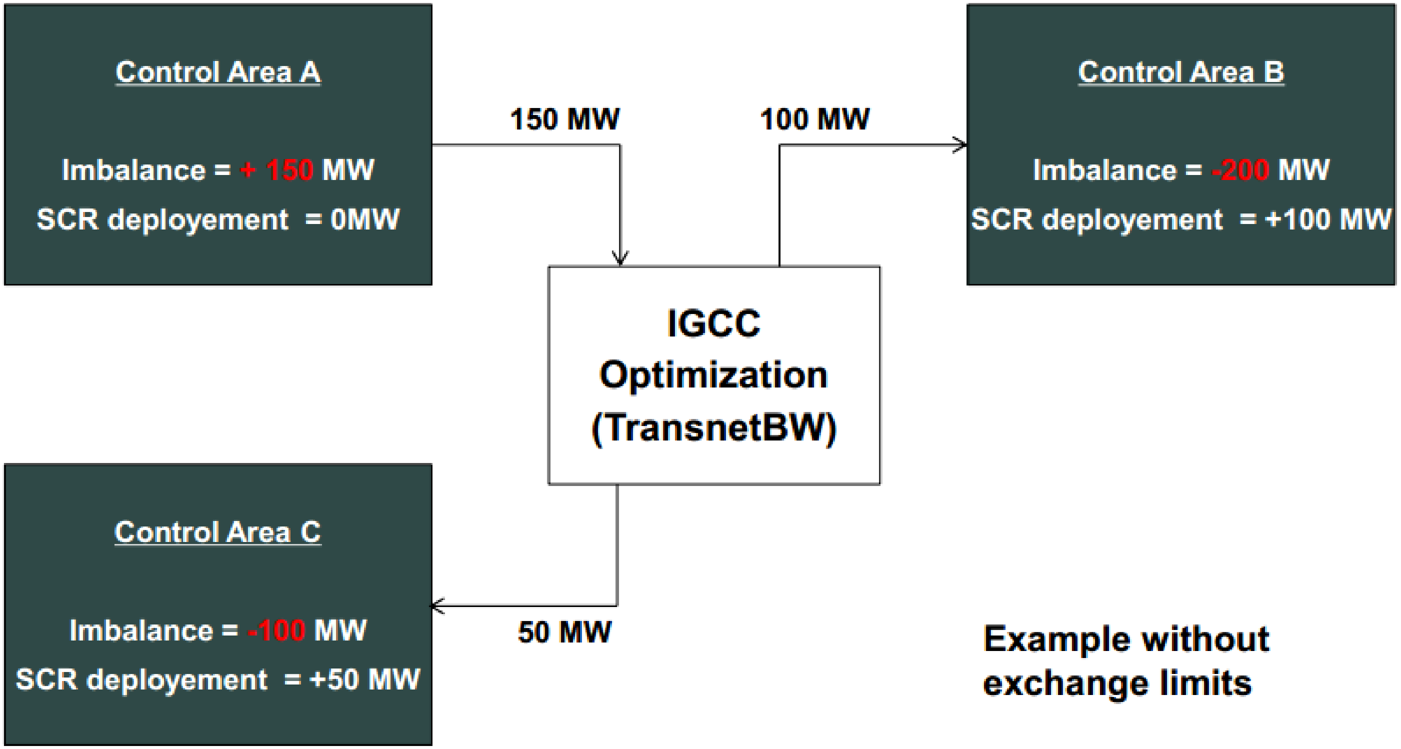
R3 Dynamic profile (max. 100 MW, only up)

ICH Demand Curtailment (261 MW, only up)

Inter TSO reserves (250 MW, not guaranteed)

International Cooperation: IGCC

- Netting of cross-border imbalance
  - Germany, Belgium, The Netherlands
  - Not guaranteed



Example without exchange limits

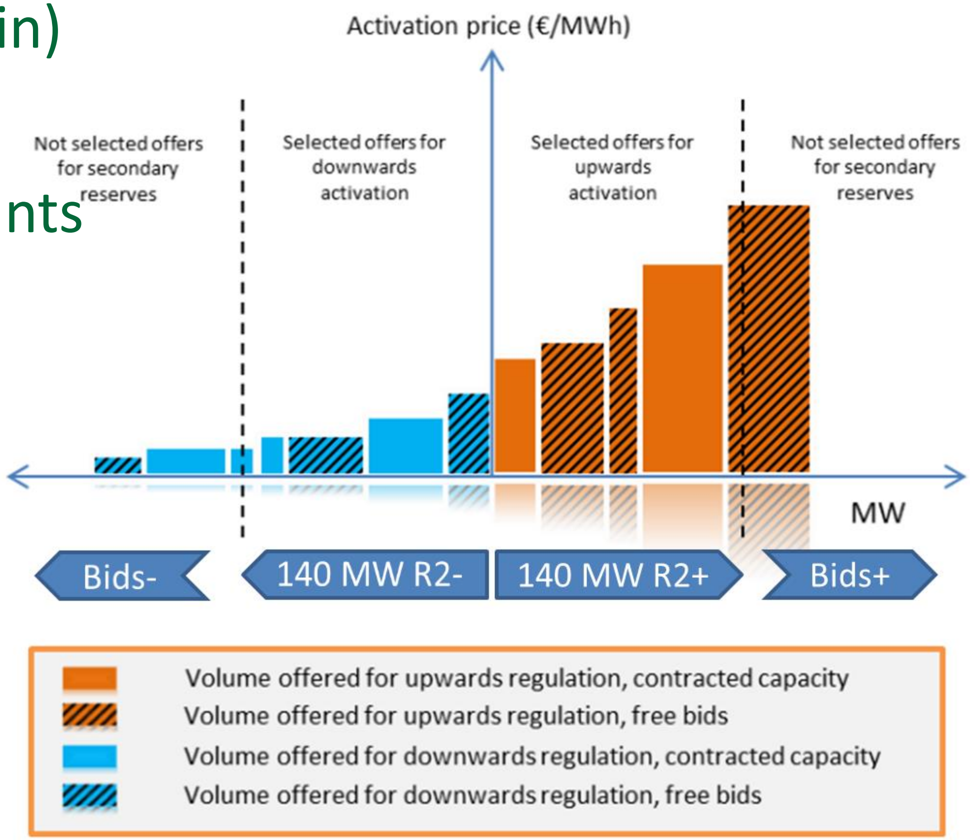
FCR – R1

- Automatic and decentralized modulation of generation profile based on frequency deviations.
  - Very fast response (seconds)
  - Transmission level
  - Monthly Tender: Reservation price [€/MW]

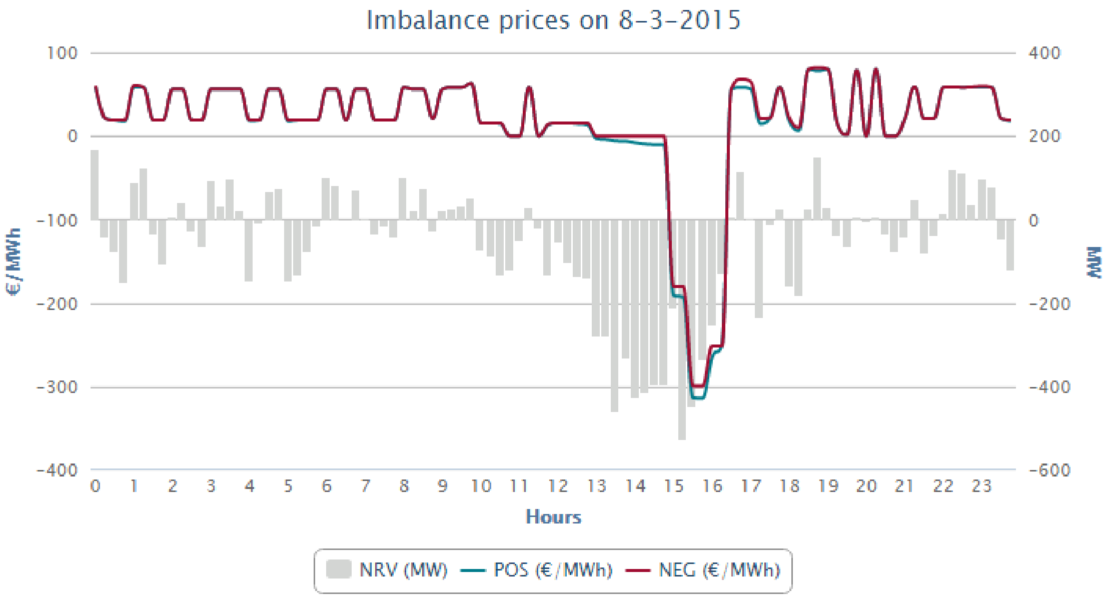
    - Conventional power plants
    - Industrial demand and aggregators (asymmetric)
    - International providers

FRRa – R2

- Automatic and central activation of reserve capacity based on Area Control Error
  - Fast response (sec to min)
  - Transmission level
  - Conventional power plants
    - Monthly tenders
      - Reservation price
      - Capped activation price
    - Free bids
      - Not guaranteed
      - Free activation price

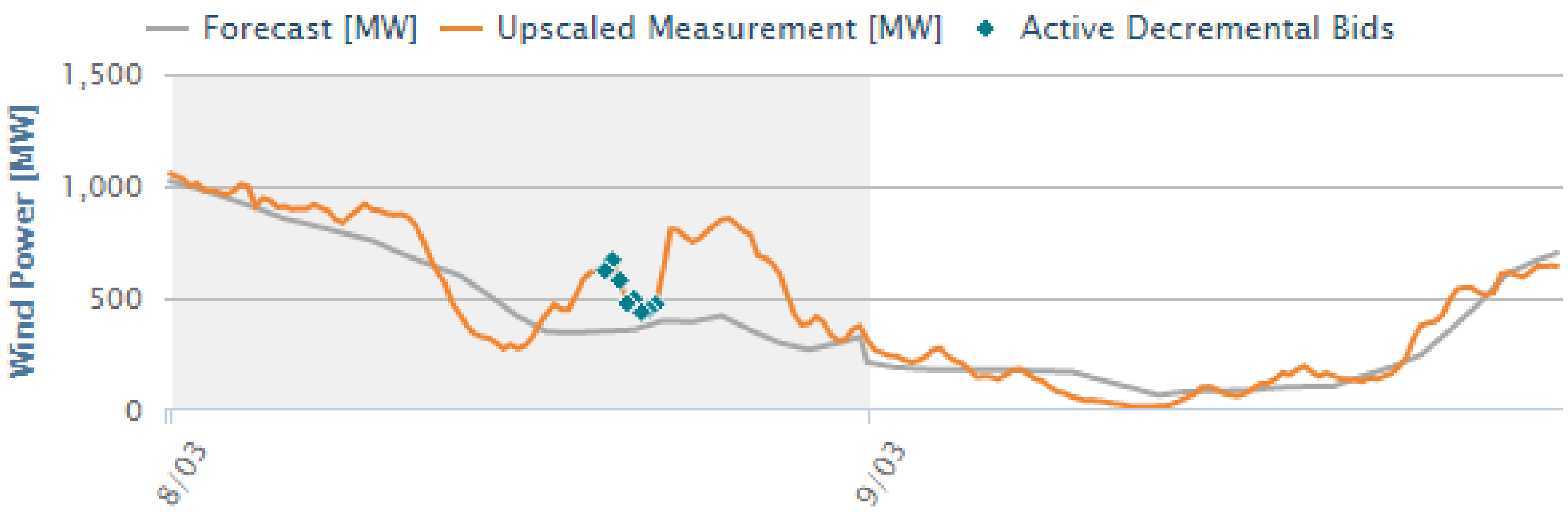


FRRa, free bids



Wind power curtailment to balance the grid

Negative price bid wind power generators



FRRm – R3

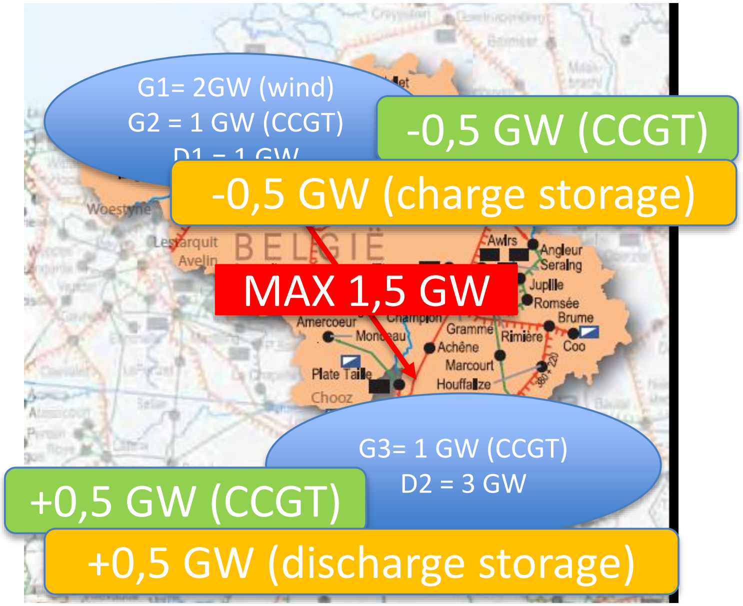
- Manual and central modulation of generation in order to relieve R2
  - Response (minutes)
  - Transmission and distribution level
  - Monthly Tender
    - reservation price [€/MW]
    - Activation price [€/MWh]
  - Technologies
    - Conventional power plants
    - Industrial demand (ICH) and aggreggators (R3DP)
    - Inter-TSO reserves

Congestion Management (TSO)

- Re-dispatch mechanism
  - Day-ahead nominations
  - TSO load flow analysis
  - Re-dispatch power plants

- CIPU contract
  - Power plants (bidding available capacity at cost)
  - Merit order activation

- Storage, if at right location, can provide congestion management services



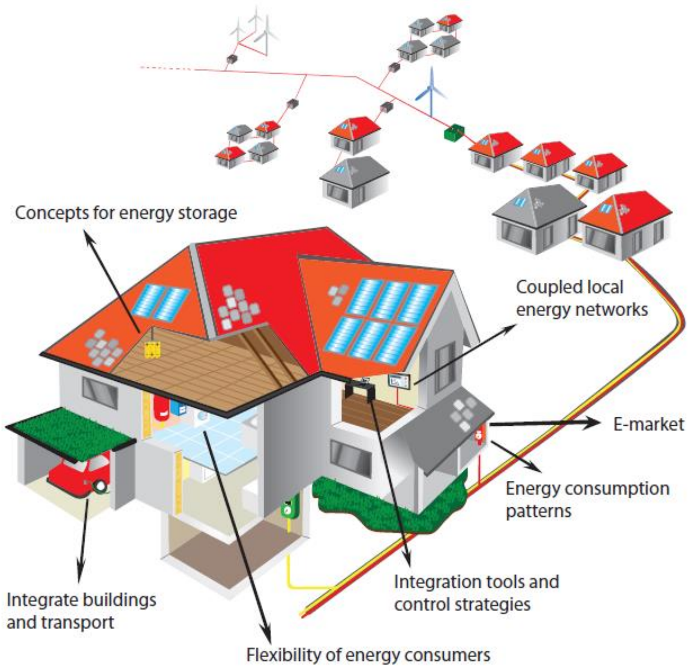
Voltage control (TSO)

- Reactive power
  - By-product of active power
  - Not useful, but line congestion
  - Impact on voltage level
  - Local balancing required

- Voltage and reactive power control
  - Transmission assets (TSO)
  - Power plants services (Generators)
    - Tenders with reservation and/or activation price
    - Grid code requirements for grid users
    - Potential service for large scale storage
    - Ex. Coo-Trois-Ponts

Congestion and Voltage Management (DSO)

- New electric applications
  - Electric vehicles and heat pumps
    - Increasing consumption
    - Demand response



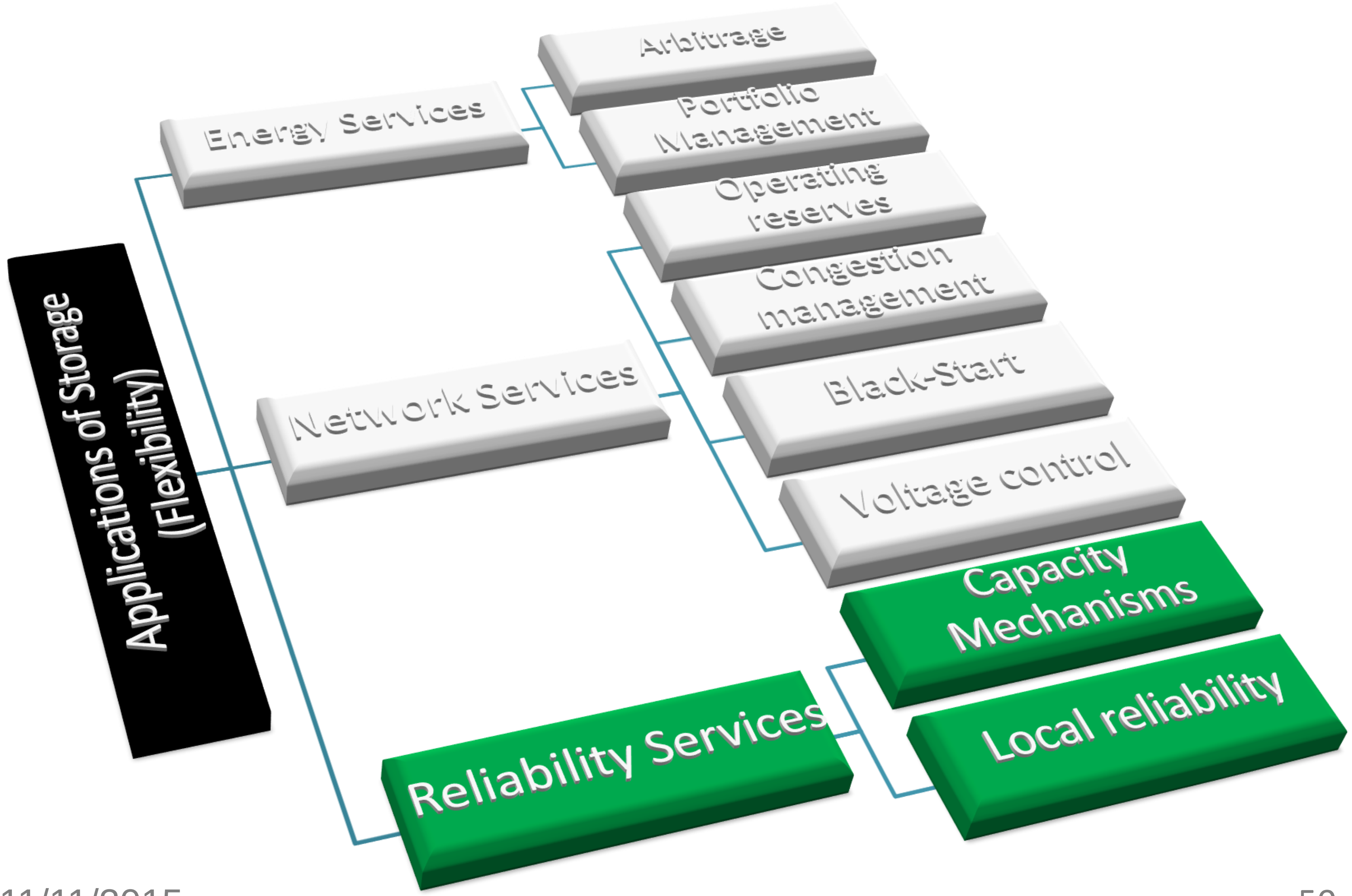
- Distributed generation
  - Photovoltaic and wind power
  - Increasing injections

- Trade-off: storage as an alternative for grid investments
    - Distribution grid
    - Local: stand-alone batteries and electric vehicle
    - No market framework in place in Belgium
    - Linear project:
      - Tariff based
      - Incentive based

Black Start

- After a large black out
  - TSO needs to gradually restart the system
  - Units with independent power supply
  - Electrical storage (e.g. Coo-Trois-Ponts)
- Tendering procedure
  - Contracts for multiple years
  - Meet technical criteria (> 200 – 300 MW)
  - Fixed cost: additional investments and tests
  - Variable cost: opportunity cost

Applications in a liberalized market

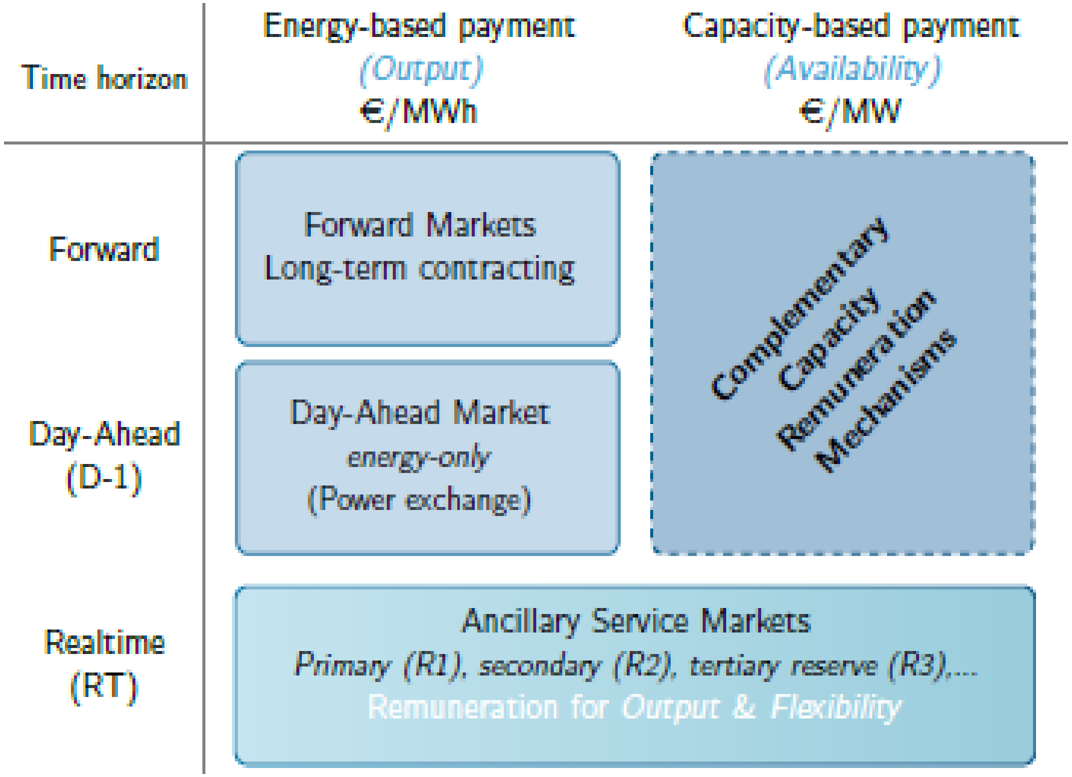


Capacity Remuneration

Capacity Remuneration Mechanism

- Instrument ensuring adequate level of generation capacity
- Complementary mechanism besides the energy market influencing the volume and capacity through remuneration available capacity
- Additional revenue streams valuing the installed capacity [€/MW]

Capacity remuneration



Höschle, 2014

Potential explanation:

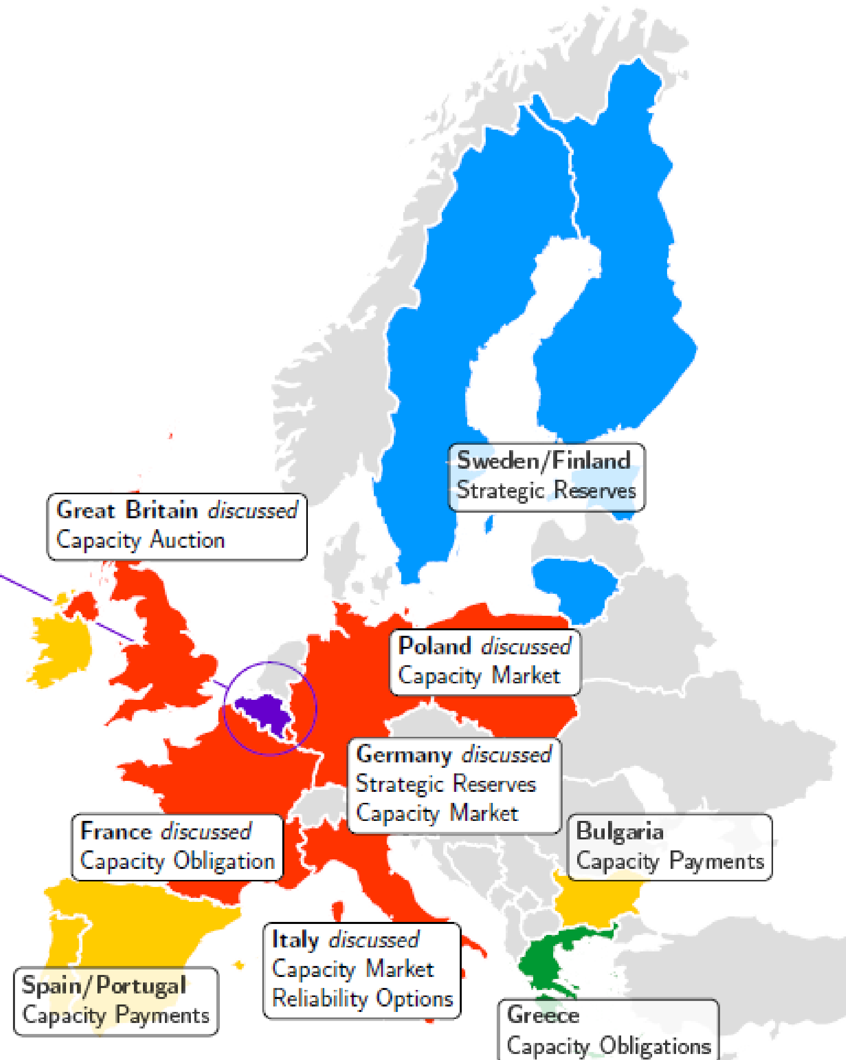
- Market design
- Overcapacity
- Market power
- Energy policy

Capacity remuneration mechanisms as complementary adaptation if existing markets fail to create adequate investment climate

European Situation

Belgium: Strategic Reserves

- Situation in Belgium
  - Nuclear phase-out in stages until 2025
    - Total installed capacity of 5926 GW (~35% in June 2013)
  - Increased share of RES
    - Share of total generated electricity 8.9% in 2012 (4.8% in 2007)
  - **Threatened system adequacy**
- Plan Wathelet
  - Secretary of State in charge of environment, energy and mobility
    - *Melchior Wathelet*
  - Issued in June 2012, accepted by the government in July 2013
    - **Strategic reserves to ensure security of supply**



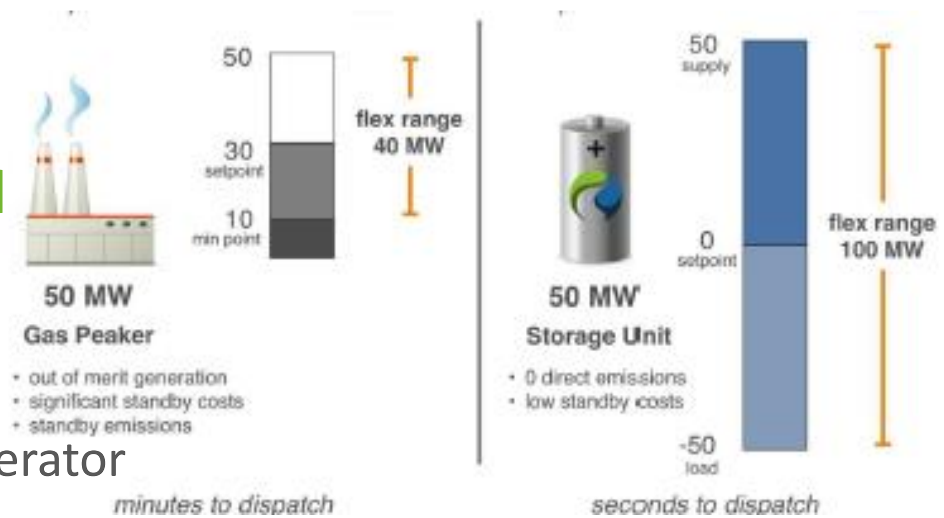
Höschle, 2015

Capacity remuneration and storage

- Strategic reserves in Belgium
  - 2014-2015
    - All production units for which closure is announced, and all units which are temporarily shut down (750 MW)
    - Demand response products (100 MW)
    - Day-ahead signal (warm up period), activation signal
  - 2015-2016
    - Additional 2750 MW
    - 300-500 MW from power plants (2 years)
    - Additional capacity (1 year)
    - Downward revision if Doel 3 or Tihange 2 re-commissioned

Local reliability

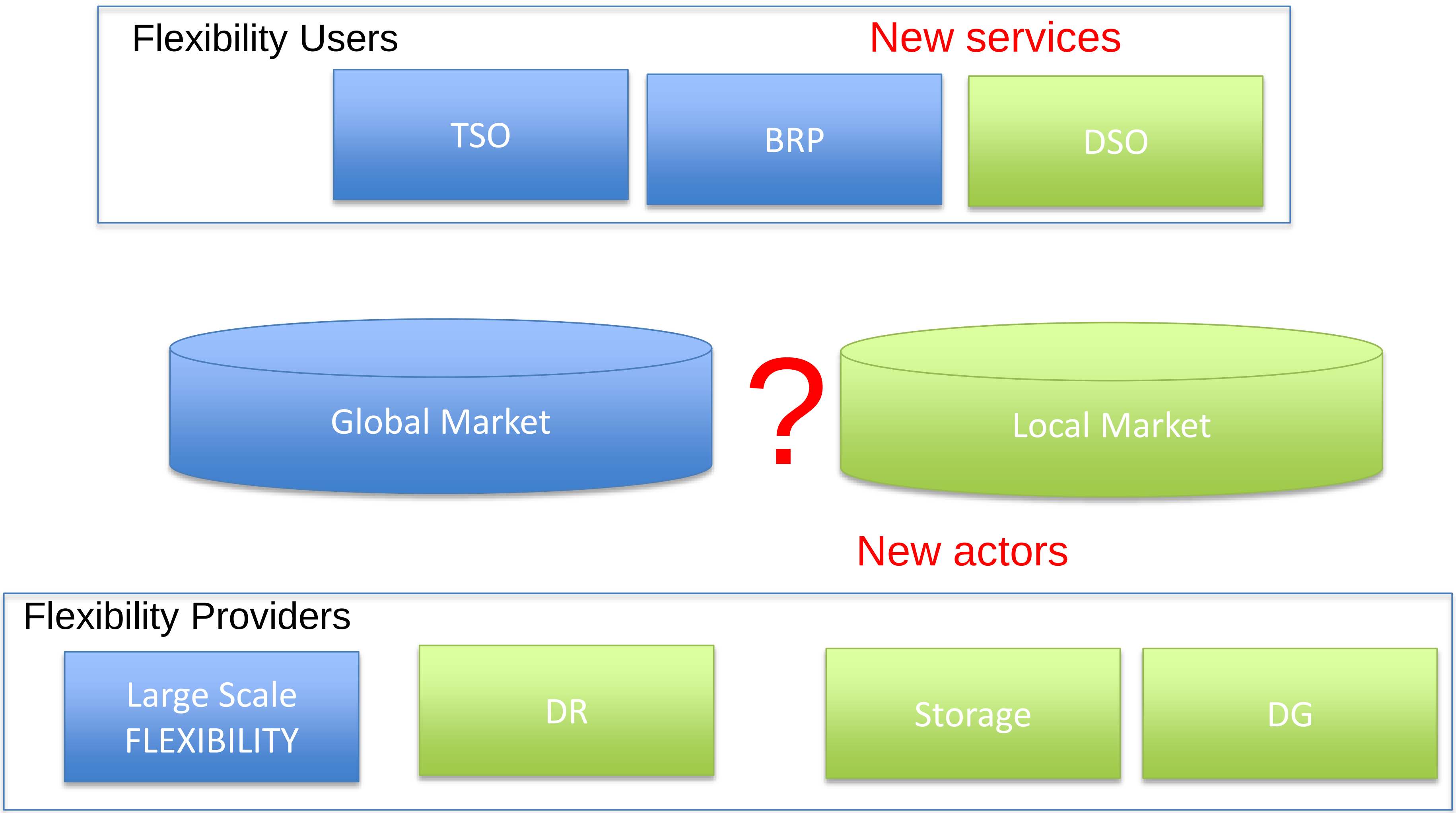
- Value of providing improved reliability
  - Back-up power source
    - Value of lost load
    - Alternative to back-up generator
      - Strategic infrastructure
      - Industrial processes
  - Microgrid applications
    - Local generation with storage
    - Specific applications, e.g. remote areas (Princess Elisabeth Station)
  - Power management system



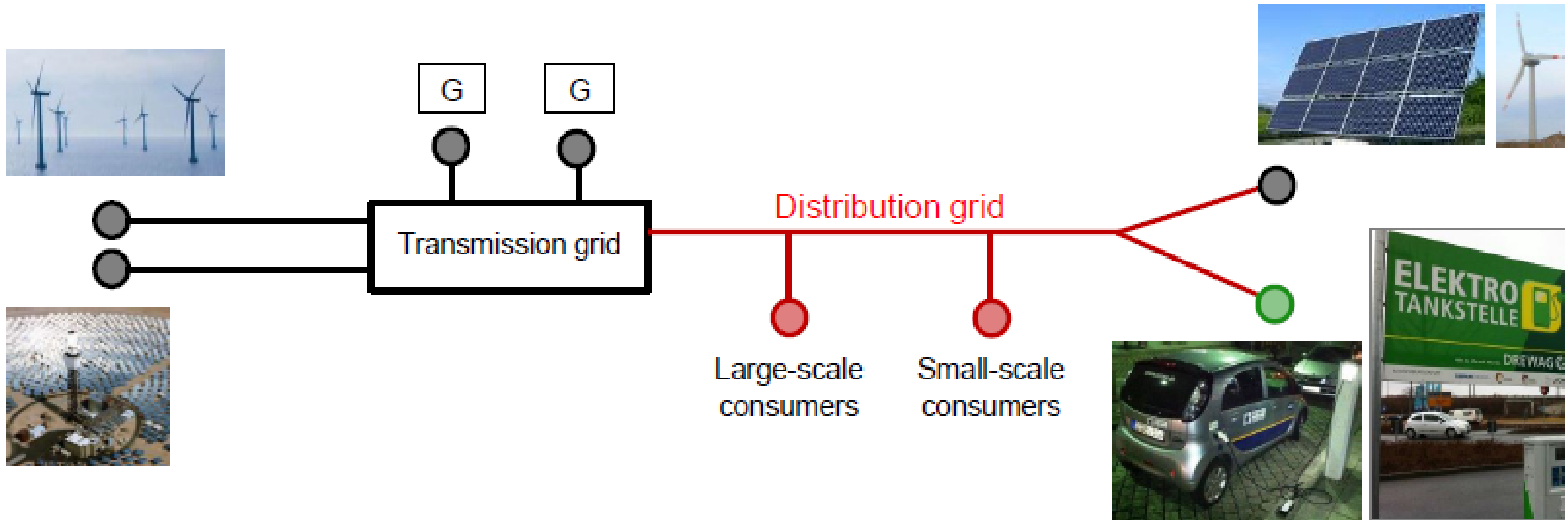
Chet Lyons, 2014

Princess Elisabeth Antarctica Research Station

Markets for Flexibility



Which technology and where to put it…



Drivers of system change on T and D level:

- Connection of large-scale RES
- Increasing system interconnection

- Distributed generation
- Smart applications, smart contracts, smart grids, etc.
- Increasing penetration of electric vehicles

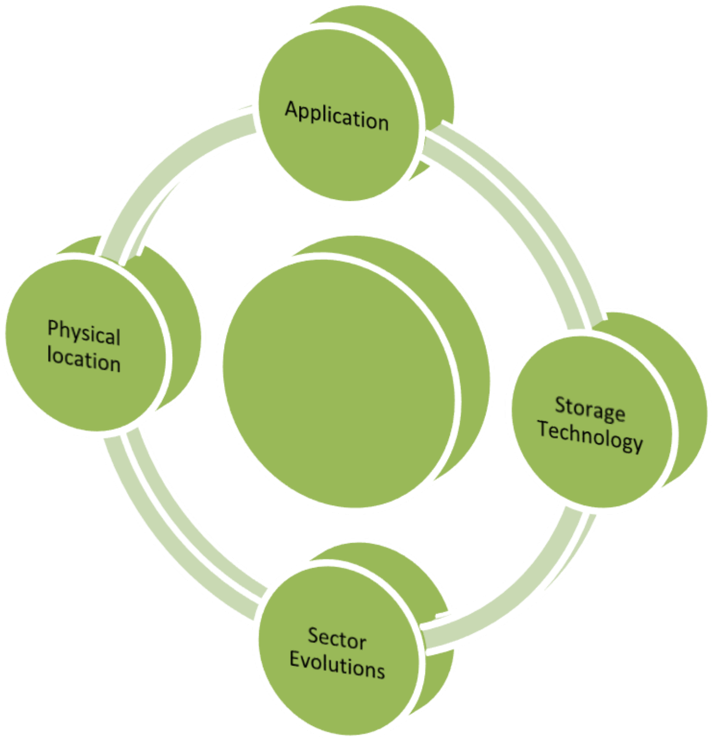
Reuster, 2012

Interplay

Economic aspects: building a feasible business case for storage

Variety of applications in current electricity market

- Energy and network services
- Move away from classic applications such as day and night arbitrage
- Mover towards operation strategies optimizing revenues over different markets



EnergyVille

PART IV.

REGULATORY AND ADMINISTRATIVE BARRIERS

Regulatory and Administrative Barriers

- Unbundling
  - Specific definition of storage is required ⇔ generation or demand
  - Determine storage as market or regulated activity
- Storage products
  - Market framework should allow products and services which allow efficient operation of storage
- Capacity Remuneration Mechanisms
  - Participation of storage in capacity remuneration mechanisms
  - Interaction with electricity market

Market Design

Network Tariffs

Framework Network Operators

Administrative and Political Barriers

Regulatory and Administrative Barriers

- Network tariff design
  - Injection versus off-take
  - Impact on profitability storage
  - Harmonization
- Distribution Tariffs
  - Lack of a regulatory framework
  - Storage connected o the distribution level
  - Interaction with consumption and injection tariffs for local storage

Market Design

Network Tariffs

Framework Network Operators

Administrative and Political Barriers

Regulatory and Administrative Barriers

Remuneration Framework

- Drives innovation of regulated parties (e.g. contracting system services from new technologies)

- Cost-based and Performance-based remuneration do not incentivize innovation

Market Design

Network Tariffs

Framework Network Operators

Administrative and Political Barriers

Regulatory and Administrative Barriers

Permitting Procedures
- Impacts project lead time
- Uncertainty

Energy Policy
- Stable regulatory and market framework such as network tariffs, levies and support mechanism.
- Stable electricity sector evolutions such as a consistent nuclear phase-out policy

Ensuring Stable Revenues
- Long term contracts for network services reduce the investment risk but act as a potential entry barrier for competitors (⇔ trend).

Market Design

Network Tariffs

Framework Network Operators

Administrative and Political Barriers

Policy Recommendations

- There is need for a **quantitative study towards the need for flexibility** on long, medium and short term. This requires an evolution of current methodologies.

- A **market and regulatory framework** is a key element for the operation of electricity storage. This framework does preferably not discriminate between different providers of flexibility.

Policy Recommendations

- PHS are, due to their maturity and large-scale, an interesting technology for providing flexibility to the transmission system level. **A potential extension of the PHS capacity requires a detailed cost-benefit analysis.**

- Batteries provide, due to expected market evolutions, large potential for the distribution system level. **Potential of distributed storage should be studied together with the evolution towards electrical vehicles and thermal storage**.

Questions?

e-mail: Kristof.DeVos@kuleuven.be
website: http://www.kuleuven.be/wieiswie/en/person/00060433